

ARMY RESEARCH LABORATORY



Standard and Alternate Methods of Stretcher Carriage: Performance, Human Factors, and Cardiorespiratory Responses

Joseph J. Knapik
William H. Harper
Harrison P. Crowell
Kathy L. Leiter
Bradley T. Mull

ARL-TR-1596

JANUARY 1998

19980324 039

DTIC QUALITY INSPECTED 4

Chatillon® is a registered trademark of Chatillon Scale Company.

Oxylog2® is a registered trademark of P.K. Morgan Limited.

Polar Vantage XL® is a registered trademark of Polar Electro Oy.

Warren Collins® is a registered trademark of Warren Collins, Inc.

The findings in this report are not to be construed as an official Department of the Army position
unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of
the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

ARL-TR-1596

January 1998

Standard and Alternate Methods of Stretcher Carriage: Performance, Human Factors, and Cardiorespiratory Responses

Joseph J. Knapik

U.S. Army Center for Health Promotion and Preventive Medicine

William H. Harper

Harrison P. Crowell

Kathy L. Leiter

Bradley T. Mull

Human Research & Engineering Directorate, ARL

Approved for public release; distribution is unlimited.

Abstract

Eleven soldiers performed two-person carries of a stretcher containing an 80-kg manikin while walking on a treadmill set at 4.8 km/hr. In separate trials, soldiers carried the stretcher using one of four methods involving (a) traditional hand carriage, (b) shoulder straps (cross-shoulder system), (c) a specially designed harness that allowed load shifting between the hips and shoulders (hip-shoulder system), and (d) a clip that fit on the pistol belt of military load-carrying equipment (LCE) and placed the stretcher mass mainly on the hips (LCE system). With each system, subjects walked until fatigued or until 30 minutes expired. While subjects walked, their expired gases and heart rates were obtained and subjects rated their perceived exertion (Borg Scale). At the conclusion of all four trials, subjects rated each system on a number of subjective measures. Average (SD) carriage times (in minutes) were 2.7 ± 1.4 , 14.5 ± 8.3 , 25.4 ± 8.1 , and 21.7 ± 9.9 with the hand, cross-shoulder, hip-shoulder, and LCE-integrated systems, respectively. Hand carriage resulted in considerably more cardiorespiratory stress (higher heart rate and minute ventilation) than the other three systems, but there were few consistent differences among the other three systems. Perceived exertion in the upper body was less with the hip-shoulder and LCE systems than with the other two systems, and subjects preferred the hip-shoulder and LCE integrated systems overall, as well as for specific characteristics including comfort, ease of use, and stability. These data indicate that two-person stretcher carriage methods that displace the load from the hands to the shoulders and hips improve performance, reduce cardiorespiratory stress, and are preferred by subjects. Further developmental work should focus on the hip-shoulder and LCE systems.

FOREWORD

The U.S. Army currently has 277 military occupational specialties (MOSs) (Headquarters, Department of the Army, 1994). More than 124 (45%) of these MOSs are classified as "very heavy" by the Department of Labor (DOL) strength standards (DOL, 1991). The "very heavy" classification is the highest in the DOL rating scheme and is reserved for jobs that require occasional lifting of 100 pounds or more and frequent lifting of 50 pounds or more. MOSs with very heavy lifting requirements comprise a large proportion of the total Army manpower, accounting for most of the enlisted slots (Headquarters, Department of the Army, 1994). Personnel availability can be negatively impacted by tasks with heavy physical requirements since these requirements can often exclude a large number of otherwise fully capable individuals from entering or being retained in these MOSs. An indication of the potential severity of the problem is the fact that pre-enlistment testing demonstrates that approximately 14% of the volunteer military age male population are not capable of the DOL "very heavy lifting" standard to the height of a standard military truck and very few military age women are capable of such lifting (Sharp, Wright, & Vogel, 1985).

We previously developed a process for identifying physically demanding tasks within specific MOSs and characterizing potential methods of redesigning those tasks to make them less physically demanding (Knapik, et al., 1997). Steps in the process included (a) a review of relevant publications (e.g., soldier training publications [STPs], Army training and evaluation programs [ARTEPs], programs of instruction [POIs], etc.) to identify physically demanding tasks, (b) an interview of soldiers regularly performing in the MOS, and (c) a videotape of soldiers performing tasks identified as the most physically demanding. Once redesigns were identified, they were tested in consultation with project managers or appropriate individuals from the schools involved with the MOS.

As part of this process, we tested several alternate methods of stretcher carriage because this was one of the most physically demanding tasks identified by medical specialists (MOS 91B). Also, a review of other publications revealed that this was a common task that virtually all soldiers may be called upon to perform. This report describes an engineering design that improves stretcher carriage performance and reduces the physical demands on the carrier. We present previous work in this area, our study design to test alternate methods of carriage, the results of our efforts, and recommendations for future work.

ACKNOWLEDGMENTS

We would like to thank Mr. Samson Ortega and Mr. Charles Hickey for excellent technical assistance during the data collection phase of the study. The help of Major David Shephard in allowing ordnance soldiers to participate in the study is also gratefully acknowledged.

Mr. Dennis Hash provided outstanding engineering support. He built many of the devices used in this study, including the wooden frame that held the stretcher, the LCE integrated clip, and the hip-shoulder harness.

Lieutenant Colonel Valerie Rice consulted with us about harness designs and study design and provided her harness prototypes, which immeasurably aided in the design of our prototypes. She also reviewed the final manuscript.

Thanks also to Ms. Shelby Choate for the drawings of the four stretcher carriage methods and Mr. Mike Kosinski for the detailed drawings of the hip-shoulder harness.

CONTENTS

EXECUTIVE SUMMARY	5
INTRODUCTION	9
BACKGROUND	9
OBJECTIVE	11
METHODS	11
Participants	11
Experimental Conditions	11
Study Design	13
Pre-testing	13
Stretcher Carriage: Familiarization	16
Stretcher Carriage: Experimental Trials	17
Post-Study Questionnaires	19
RESULTS	20
Stretcher Carriage Times	20
Cardiorespiratory and Rating of Perceived Exertion (RPE) Measures During Treadmill Walks	20
Hand Grip Strength Before and After Stretcher Carriage	28
Post-Exercise Ratings of Pain, Soreness, and Discomfort	29
Responses to Utility Questionnaire Upon Completion of Stretcher Carriage Trials	33
Responses to Paired Comparison Questionnaire Upon Completion of Stretcher Carriage Trials	35
Pre-Test Measures	35
Factors Accounting for Hand Carriage Performance	36
DISCUSSION	37
General Findings	37
Ratings of Pain, Soreness, and Discomfort (PSD)	38
Cardiorespiratory Responses During Hand Carriage	39
Cardiorespiratory Responses With Alternate Stretcher Carriage Methods	41
Factors Accounting for Hand Carriage Performance	44
Pre- and Post-Exercise Hand Grip	47
Observation of Fatigue Manifestation in Hand Carriage	48
RECOMMENDATIONS	48

REFERENCES	51
----------------------	----

APPENDICES

A. Rating of Perceived Exertion	57
B. Soreness, Pain, and Discomfort Questionnaire	61
C. Utility Questionnaire	65
D. Paired Comparison Questionnaire	69
E. Descriptive Statistics for the Pre-Test Measures	73

DISTRIBUTION LIST	77
-----------------------------	----

REPORT DOCUMENTATION PAGE	87
-------------------------------------	----

FIGURES

1. The Four Litter Carriage Methods Tested: (a) Hand Carriage, (b) Cross-Shoulder Carriage, (c) Hip-Shoulder Carriage, and (d) LCE Integrated Carriage	12
2. Overall Setup for Testing the Stretcher Carriage Methods	18
3. Heart Rate During Walking With Four Methods of Stretcher Carriage	22
4. Oxygen Consumption During Walking With Four Methods of Stretcher Carriage	23
5. Ventilation During Walking With Four Methods of Stretcher Carriage	24
6. Ventilatory Equivalent During Walking With Four Methods of Stretcher Carriage	25
7. Upper Body RPE During Walking With Four Methods of Stretcher Carriage	26
8. Lower Body RPE During Walking With Four Methods of Stretcher Carriage	27
9. Hand Grip Strength Before and After Walking With Four Methods of Stretcher Carriage (mean \pm SE)	29
10. PSD Ratings (posterior) After Walking With Four Methods of Stretcher Carriage	30
11. PSD Ratings (anterior) After Walking With Four Methods of Stretcher Carriage	30
12. Combined PSD Ratings After Walking With Four Methods of Stretcher Carriage	32
13. Utility Questionnaire Responses After Completing Exercise With All Four Stretcher Carriage Methods	34
14. Scaled Indices for the Stretcher Carriage Methods	35

TABLES

1. Individual Data and Group Descriptive Statistics for Stretcher Carriage Times (minutes)	21
2. Number of Subjects at Each Time Point During the Four Stretcher Carriage	

Conditions (these are the number of subjects used in graphing the cardio-respiratory data)	22
3. Heart Rate Data Comparing Stretcher Carriage Methods	23
4. Oxygen Consumption (VO_2) Data Comparing Stretcher Carriage Methods . . .	24
5. Minute Ventilation (V_e) Data Comparing Stretcher Carriage Methods	25
6. Ventilatory Equivalent (V_e/VO_2) Data Comparing Stretcher Carriage Methods	26
7. Upper Body RPE Data Comparing Stretcher Carriage Methods	27
8. Lower Body RPE Data Comparing Stretcher Carriage Methods	28
9. PSD Data (anterior aspect of body) After the Treadmill Walk Comparing Stretcher Carriage Methods	31
10. PSD Data (posterior aspect of body) After the Treadmill Walk Comparing Stretcher Carriage Methods	31
11. Pain, Soreness, and Discomfort Data (combining body parts) After the Treadmill Walk	33
12. Responses to the Utility Questionnaire After Completing Exercise With All Four Stretcher Carriage Methods	34
13. Paired Comparison Questionnaire Incidence Matrix	35
14. Regression Coefficients, Confidence Intervals, and Multiple R-Value	36
15. Oxygen Uptake Corrected for Stretcher Mass (VO_2 in $\text{ml} \cdot \text{kg}[\text{of body mass} + 45\text{kg}]^{-1} \cdot \text{min}^{-1}$)	44
16. Correlations Between Strength and Various Estimates of Cross-Sectional Muscle Mass	45
17. Correlations Between Hand Carriage Time and Various Strength and Physical Performance Variables in Two Independent Studies	46

EXECUTIVE SUMMARY

The requirement to transport casualties is a common soldiering task described in almost all Army test and evaluation program (ARTEP) manuals as well as in the Soldier's Manual of Common Tasks. One of the most common ways to transport a wounded or otherwise incapacitated individual is by stretcher. This allows the casualty to be moved in a comfortable supine position and allows medically trained personnel access to the body. The traditional hand carriage method of stretcher carriage can be sustained for only short periods of time because the heavy stretcher mass is placed on the small muscle groups of the forearm and hands, and these muscle groups fatigue rapidly. In this investigation, we tested several alternate methods that moved the load from the smaller muscle groups of the forearms and hands to the larger muscle groups of the shoulders and hips. We quantified the extent to which these stretcher carriage methods altered performance, cardiorespiratory stress, and subjective impressions of exertion and comfort.

Subjects were 11 soldiers (seven men and four women) who performed two-person stretcher carries using four different methods. The baseline method was called "hand carriage," which is the traditional method for carrying most stretchers. The second method was called "cross-shoulder carriage." This method used a harness consisting of two independent straps that crisscrossed the shoulder and extended to the hips. At the hip ends of the straps were aluminum hooks that held the stretcher handles. The stretcher mass was carried primarily on the subjects' shoulders. The third method was called "hip-shoulder carriage." This method used a harness consisting of well-padded shoulder straps attached to a well-padded hip belt. Buckle adjustments allowed the load to be shifted between the hips and shoulders. Two sets of fabric loops on both sides of the hip belt were used to hold the stretcher handles. The final method was called the load-carrying equipment (LCE) integrated carriage. This method used a metal clip with a fabric loop that attached to the pistol belt of the individual integrated fighting system (IIFS). The fabric loops held the stretcher handles. Four of these attachments were used, two connected to each side of the pistol belt. The pistol belt was adjusted so that most of the load rested on the hips.

Subjects were pre-tested to obtain anthropometry, estimated whole-body composition, estimated muscle cross-sectional areas, muscle strength, and physical fitness (Army Physical Fitness Test). After this, they were familiarized with the carriage systems and experimental procedures by walking on a treadmill with each system for 5 minutes and performing all procedures as they would during the experimental sessions.

During the experimental sessions, one subject tested one system per day and he or she had at least 48 hours of rest between trials. In each session, the subjects walked on a motor-driven treadmill set at a pace of 4.8 km/hr (3 miles per hour), while they carried a stretcher holding an 80-kg manikin. The subjects walked in the forward position (facing away from the stretcher) with the rear portion of the stretcher supported by straps attached to a wooden frame. Each subject continued to walk and carry the stretcher until voluntary fatigue or until he or she had walked 30 minutes. After 30 minutes, the test was stopped by the investigators. While the subject was walking, heart rate, oxygen uptake, ventilation, and a rating of perceived exertion (RPE) were obtained every minute for the first 5 minutes, at 7.5 minutes, 10 minutes, and every 5 minutes thereafter. Before and immediately after the treadmill walk, the subjects' right and left hand grip strength was tested. After the subjects had completed the hand grip test and removed the harnesses and test equipment, they completed ratings of pain, soreness, and discomfort (RPSD). This questionnaire asked them to rate 22 body parts for any pain, soreness, or discomfort they were currently feeling.

After performing all four stretcher carriage trials, the subjects completed a stretcher utility questionnaire that contained several questions regarding comfort, ease of use, ease of carrying, overall stability, usefulness in the field, and effort required. Subjects rated each of the four stretcher carriage methods for these characteristics. They also completed a paired comparison questionnaire that required them to make a forced choice among pairs of stretcher carriage methods.

Average (SD) carriage times (in minutes) were 2.7 ± 1.4 , 14.5 ± 8.3 , 25.4 ± 8.1 , and 21.7 ± 9.9 with the hand, cross-shoulder, hip-shoulder, and LCE systems, respectively. Heart rate and ventilation were considerably higher during the short hand carriage period when compared to all three other carriage methods ($p < 0.01$); this indicated considerably more cardiorespiratory stress and possibly more lactate accumulation in the hand carriage condition. There were few cardiorespiratory differences between the other carriage methods. Upper body RPE was considerably higher during hand carriage than during all the other carriage methods ($p < 0.01$). Upper body RPE was also higher for the cross-shoulder method than for the hip-shoulder and LCE methods ($p < 0.05$).

The RPSD suggested that the carriage methods were successful in transferring the stretcher mass to the body areas expected. For hand carriage, RPSD were highest in the hands and arms. For cross-shoulder carriage, ratings were highest in the neck, shoulder, and upper trunk areas. For both the hip-shoulder and LCE carriages, ratings were highest in the hips, lower trunk, and in the legs. The LCE method resulted in higher RPSD in the hip and lower trunk, compared

to the hip-shoulder method; the hip-shoulder method had higher RPSD in the shoulder and upper trunk compared to the LCE method.

On the utility questionnaire, soldiers rated the hip-shoulder and LCE methods more favorably than the hand and cross-shoulder methods for comfort, ease of use, ease of carry, overall stability, usefulness in the field, and effort required. There were no differences between the two former methods on any of these questions. Analysis of the paired comparison questionnaire indicated that subjects preferred the hip-shoulder and LCE methods to hand and cross-shoulder carriage by a large margin.

These data indicate that the hip-shoulder and LCE methods result in longer performance times, lower perceived exertion in the upper body, and are preferred by subjects over the cross-shoulder and hand carriage methods. The former methods also considerably reduce cardiorespiratory strain when compared to hand carriage. There were indications of slightly longer performance times with the hip-shoulder method when compared to the LCE method. However, the LCE method has the advantage of fitting into existing Army load-carrying equipment, providing a strong practical benefit over the hip-shoulder method. With the LCE method, soldiers can take a relatively light piece of equipment to the field, attach it to equipment he or she is already wearing, and substantially increase stretcher carriage times while lowering effort.

We recommend that further developmental work be continued on the hip-shoulder and LCE systems. While the LCE system is most practical in field environments, the hip-shoulder system may have uses in civilian endeavors and in specific military garrison environments where soldiers are not wearing their LCE. The hip-shoulder harness could be improved by providing lateral stiffeners in the hip belt that may help reduce point pressures on the hips. It may be possible to improve the LCE system by providing a broader, plastic clip and minimizing mass on the lower portion of the clip. Providing appropriate padding on the lower part of the system may also help. Open metal hooks should replace the closed fabric loops on both systems in order to allow the carrier to more easily place and displace the stretcher handles. After these changes are made and pilot tested, the systems should be tried in a realistic test environment. This would involve examining the full range of stretcher carriage activities including placing the manikin on the stretcher, lifting the stretcher, walking with it, and placing it into an ambulance.

STANDARD AND ALTERNATE METHODS OF STRETCHER CARRIAGE: PERFORMANCE, HUMAN FACTORS, AND CARDIORESPIRATORY RESPONSES

INTRODUCTION

The requirement to "evacuate wounded" or "transport a casualty" is a familiar soldiering task described in virtually all Army test and evaluation program (ARTEP) manuals (e.g., ARTEP 55-188-30-DRILL, ARTEP 8-449-30-MPT, ARTEP 43-007-30-MPT) as well as the Soldier's Manual of Common Tasks. In a previous study from this laboratory (Knapik, et al., 1997), investigators were consistently told by medics (MOS 91B) that carrying casualties was one of the most physically demanding tasks they performed. One of the most common ways to transport a wounded or otherwise incapacitated individual is by stretcher. This allows the casualty to be moved in a comfortable supine position and allows medically trained personnel access to the body.

The traditional and most common method of carrying a stretcher is by hand. This type of carriage can be sustained for only a short period of time (Lind & McNicol, 1968; Rice, Sharp, Tharion, & Williamson, 1996a), because it places the load of the stretcher on the small muscle groups of the forearm and hands which fatigue rapidly. Methods have been developed for transferring the load to other parts of the body, allowing stretcher carriage to be sustained for longer periods of time (Lind & McNicol, 1968; Rice, Sharp, Tharion, & Williamson, 1996b). Longer carriage times allow faster evacuation of casualties to a higher echelon of medical care and reduce the exposure of the individuals performing the carrying. Recent advances in load carriage technology (Knapik, Harman, & Reynolds, 1996) may provide for further improvements, allowing even longer carriage time and more comfort for the carrier.

The purpose of this study was to test several alternate methods of stretcher carriage that move the load from the smaller muscle groups of the forearms and hands to the larger muscle groups of the shoulders and hips. We quantified the extent to which these carriage methods influenced performance, cardiorespiratory stress, and subjective impressions of exertion and comfort.

BACKGROUND

Lind and McNicol (1968) were the first to demonstrate that time to fatigue could be considerably extended when subjects used a shoulder harness to carry a stretcher. They showed that hand carriage resulted in progressive increases in blood pressure and heart rate; fatigue

ensued in an average of about 3 minutes. With a shoulder harness, only small changes in cardiovascular measures were noted and individuals were often able to continue carriage for the 15-minute limit of the study. Lind and McNicol did not provide a description of the type of harness used.

Rice and coworkers (Rice, et al., 1996a) compared three stretcher carriage methods in a simulated mass casualty situation. The performance task required subjects to move manikins 50 meters and complete as many carries as possible in 15 minutes. Investigators compared hand carriage and two types of shoulder harnesses. One of the shoulder harnesses (HX-Hook system) was preferred by subjects who rated it as easiest to use for both two- and four-person carries. For the two-person carries, more trips were completed with hand carriage; however, when total trip time was separated into carry time and lift time, carry time was faster with the harness, but lift time was faster with the hand method. Thus, with the shoulder harness, time was lost attaching the stretcher to the harness.

In another study, Rice and coworkers (Rice, et al., 1996b) examined long term stretcher carriage simulating removal of a casualty from a remote site. Longer carriage times were achieved when men and women carried an 82-kg manikin using two specially designed and well-described harnesses. Two-man carriage times to exhaustion were 4 minutes for hand carriage and 26 minutes with the harness. These same times for women were 2 and 17 minutes, respectively. In addition to lengthening the time the stretcher could be carried, there were other favorable benefits from using harnesses. On a task involving fine motor coordination, performance was higher after harness carriage; this could be important for medical personnel who may be required to perform fine motor tasks on patients after stretcher carriage. Marksmanship accuracy following the stretcher carriage tasks was higher when the harness was used (Tharion, Rice, Sharp, & Marlow, 1993), an important consideration if a soldier is required to defend himself or herself after a carry. Use of a harness also allowed the hand to be free to perform other tasks while transporting patients.

The harnesses used by Rice and coworkers (Rice, et al., 1996a; Rice, et al., 1996b) were designed to move the load from the smaller muscle groups of the hands and arms to the larger muscle groups of the shoulder and back. Subjective reports of pain, soreness and discomfort (PSD) suggest this was successful; with hand carriage, subjects reported more PSD in the hands and forearms, while with the shoulder harness, more PSD was reported in the neck, shoulders, chest, upper back, thighs, and calves (Rice, et al., 1996b). Transferring the stretcher load to larger muscle groups allows longer carriage times, presumably because the mass of the stretcher is

spread over a greater amount of muscle tissue, reducing the mass per unit of muscle tissue. Further, the load pressure (which can restrict cutaneous and inter-muscular circulation) is moved from a relatively small area on the hands, to a greater area covered by the shoulder harness, thus reducing the pressure per unit of skin area.

Improvements can be made in the shoulder harness designed by Rice and coworkers in two ways. The first is by transferring some of the load from the shoulders to the legs. This can be accomplished with a well-padded hip belt. Such a belt that binds tightly to the pelvis and puts the load on the top of the pelvis can be successful in transferring the load to the large muscle groups of the legs (Knapik & Reynolds, in press). Another improvement can be accomplished through load shifting. This can be achieved by providing easy-to-reach buckle adjustments on the harness device that allow moving the load from one muscle group to another. Load shifting allows formerly loaded muscle groups to rest while other muscle groups assume the load.

OBJECTIVE

The major objectives of this investigation were to examine performance, human factors, and cardiorespiratory responses to four methods of long-term stretcher carriage. Secondary purposes were to examine some factors that may account for stretcher hand carriage performance and to examine changes in hand grip strength following the four carriage methods.

METHODS

Participants

Subjects were 11 soldiers, seven of whom were medics and four of whom were soldiers involved in ordnance specialties. There were seven men and four women. These were all individuals who had just completed their advanced individual training (AIT) and had not yet been assigned to an operational unit. They were briefed about the purposes and risks of the study and provided their written informed consent in accordance with Army Regulation (AR) 70-21 (Headquarters, Department of the Army, 1989).

Experimental Conditions

Four types of stretcher carriage methods were tested and these are illustrated in Figure 1. The four conditions were presented in a partly counterbalanced order.

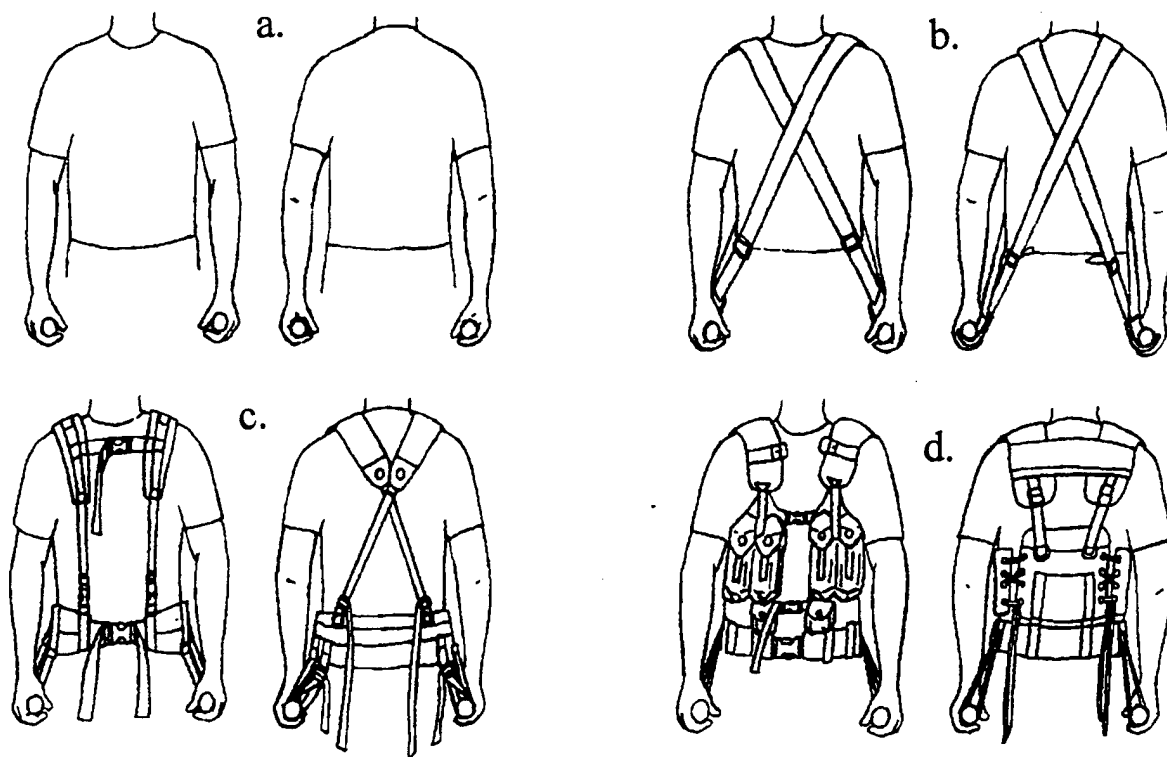


Figure 1. The four litter carriage methods tested: (a) hand carriage, (b) cross-shoulder carriage, (c) hip-shoulder carriage, and (d) LCE integrated carriage.

The baseline condition was called “hand carriage” (see Figure 1a). It is the traditional method for carrying most stretchers. The stretcher handles are held in the carriers’ hands while he or she walks.

The second condition was called “cross-shoulder carriage” (see Figure 1b). This condition involved use of a harness consisting of two independent straps that crisscrossed the shoulders and extended to the hips. At the hip ends, the straps had aluminum hooks that held the stretcher handles. The stretcher mass was carried primarily on the subjects’ shoulders. An aluminum hook at the end of each strap held the stretcher handles. The cross-shoulder strap was identical to the HX-hook design used by Rice (1992) except that additional padding was incorporated into the portion of the strap that sat on the shoulder.

The third condition was called “hip-shoulder carriage” (see Figure 1c). This condition involved the use of a harness that allowed the load to be fully or partially placed on the hips or the shoulders. Buckle adjustments allowed the load to be shifted between a well-padded hip belt around the subject’s pelvis and well-padded shoulder straps over the subject’s shoulders. Two

sets of fabric loops on both sides of the hip belt were used to hold the stretcher handles. These loops were also adjustable.

The fourth condition was called the load-carrying equipment integrated carriage or "LCE carriage" (see Figure 1d). This involved use of a metal clip with a fabric loop. The metal clip was attached to the pistol belt of the individual integrated fighting system (IIFS). The fabric loops on the clip held the stretcher handles. A total of four of these clips was used, two attached to each side of the pistol belt. In the present study, the pistol belt was adjusted so that most of the load rested on the hips. This was done because a previous study showed there was less perceived fatigue and pressure when loads are carried on the waist as opposed to the shoulders (Holewijn & Lotens, 1992).

Study Design

The study consisted of a pre-test, stretcher carriage familiarization, and four experimental trials. The four experimental trials involved the use of the four stretcher carriage conditions.

The pre-test was conducted over a 3-day period, during which time, a number of measures were obtained to characterize the subjects. Following the pretest and after at least one day of rest, a single session familiarization was conducted. During the familiarization, each of the four stretcher carriage methods was performed by the subject for 5 minutes or until fatigue occurred. Following the familiarization (and after at least a 72-hour rest), subjects carried the stretcher using each of the four methods on 4 separate days. A subject was tested on only one stretcher carriage method each day and there were at least 48 hours' rest between conditions (only two conditions per week).

Pre-testing

To fully characterize subjects and to determine factors that may account for hand carriage performance, subjects were pre-tested for anthropometry, estimated body composition, estimated cross-sectional muscle mass, and muscle strength. An Army Physical Fitness Test (APFT) was also administered. Pre-test procedures are described next.

Anthropometry

Each subject's total body mass was obtained from a digital scale and stature from an anthropometer. The subject's age at the start of the study was determined from date of birth. Other anthropometric measurements were made using the procedures of Gordon et al. (1989).

These included cervical height, acromial height, acromial height (sitting); biacromial breadth; axilla height; waist height (natural); iliocristale height; interscye I; chest height, breadth, depth, and circumference; strap length, and sitting height.

Body Composition

Body fat was determined using the equations and techniques of Vogel, Kirkpatrick, Fitzgerald, Hodgdon, and Harman (1984). For the men, circumference measures were obtained from the neck and abdominal (omthalion) areas; for women, circumference measures were obtained from the neck, forearm, wrist, and hip areas. Fat-free body mass was determined by subtracting body fat mass from total body mass.

For men, body fat was determined using the formula: Percent Body Fat = $46.89 - 68.68 (\log(S)) + 76.46 (\log(A-N))$, in which S = stature (cm), A = abdominal circumference (cm), and N = neck circumference (cm). For women, the formula was Percent Body Fat = $-35.61 - 0.52(S) + 0.17(H) - 1.58(F) - 0.53(N) - 0.20(W) + 105.33(\log(M))$, in which S = stature (cm), H = hip circumference (cm), F = forearm circumference (cm), N = neck circumference (cm), W = wrist circumference (cm), and M = body mass (kg) (Vogel, et al., 1984).

Muscle and Bone and Muscle Cross-Sectional Areas

The cross-sectional areas of bone plus muscle mass in the upper arm and forearm and the cross-sectional area of muscle mass in the thigh were estimated using anthropometric techniques. The anthropometric model for all these cross-sectional estimates assumes that the body part is circular and composed of concentric circular layers of fat plus skin, muscle, and bone tissue. Limb circumference was measured with a fiberglass tape measure. Fat plus skin thickness was measured with Harpenden skin-fold calipers. In the case of the thigh, the distance across the medial and lateral femoral epicondyle was measured with spreading calipers. Anthropometric estimates of various cross-sectional measures were obtained using equations derived from those of the area, radius, and circumference of a circle (Knapik, Staab, & Harman, 1996).

The upper arm bone plus muscle cross-sectional area was estimated using the equations of Heymsfield, McManus, Smith, Stevens, and Nixon (1982): $((C_{ua} - \pi * SF_t)^2 / 4 \pi) - 10$ (for men), and $((C_{ua} - \pi * SF_t)^2 / 4 \pi) - 6.5$ (for women), in which C_{ua} = circumference of the upper arm, and SF_t = skin fold over the triceps.

The thigh muscle cross-sectional area was measured using the methods of Knapik, Staab, and Harman (1996): $0.649((C_{th}/\pi - SF_q) - (0.3 * B_e))^2$, in which C_{th} = circumference of the thigh, SF_q = skin fold over the quadriceps, B_e = epicondyle breadth.

No validated equation exists to measure forearm bone plus muscle cross-sectional area. However, this was considered important for the present study, and the assumptions made in the estimate were similar to those of the upper arm (Heymsfield, et al., 1982) except that no empirical corrections were made. The equation was $(C_f - \pi * SF_f)^2 / 4\pi$, in which C_f = circumference over the largest portion of the forearm (near the elbow), SF_f = skin fold over the lateral portion of the largest area of the forearm (near the elbow). Please note that the anthropometric model assumes the body part is a perfect circle; the forearm violates this assumption to a greater extent than does the upper arm or thigh. This will result in an overestimate of the circumference (Knapik, Staab, & Harman, 1996), resulting in a higher absolute bone plus muscle area estimate.

Muscle Strength

Maximal voluntary hand grip strength of the right and left hand was measured with a baseline strain gauge hand grip dynamometer (Novel Products, Rockton, Illinois). The device was adjusted to produce an approximate angle of 150° at the third metacarpal-phalangeal joint and 110° at the proximal-interphalangeal joint of the third finger (Mundale, 1970). These angles could not be adjusted precisely because of the limited adjustment capabilities of the device. Subjects used the same dynamometer for all tests. They were instructed to gradually build to their maximal force in 1 to 2 seconds. They stood upright with their arms fully extended downward and the dial of the device facing the ground. They were given the verbal command "Ready? One, two, three, squeeze." Contractions were held for 3 to 5 seconds; then subjects were told to relax. Maximal force applied by the subjects was read from the dial gauge. Three to five trials were administered and the mean of the three highest (within 10% of each other) was used in the data analysis (Ramos & Knapik, 1979).

Maximal voluntary bench press, squat, and latissimus pull strength were determined using a one-repetition maximum (1 RM) procedure (Fleck & Kraemer, 1987). Subjects began lifting a light mass, and the mass was progressively increased in a systematic manner (2 to 10 kg) until a mass was found that the subject could not lift. The last mass successfully lifted with correct technique was recorded as the 1 RM. At least 30 seconds' rest were given between lifts. This procedure allowed subjects adequate warm-up before the maximal effort. During all lifts, spotters (safety personnel) were present.

Army Physical Fitness Test (APFT)

The APFT consisted of push-ups, sit-ups, and a 3.2-km run. Subjects completed as many push-ups as possible in 2 minutes, as many sit-ups as possible in 2 minutes, and ran the 3.2 km (2 miles) as rapidly as possible (in that order). At least 10 minutes' rest are allotted between events.

For push-ups, a subject lowered his or her body in a generally straight line to a point where his or her upper arms were parallel to the ground. He or she then returned to the starting point with elbows fully extended. If an individual performed a push-up incorrectly, he or she was informed of the specific error, that push-up was not counted, and the participant was allowed to continue immediately.

For sit-ups, the subject's knees were bent at a 90° angle with fingers interlocked behind the head. A second person held the participant's ankles, keeping the participant's feet firmly on the ground. For a sit-up to count, the participant must have raised his upper body to a vertical position so that the base of the neck was in front of the base of the spine and then return to the starting position. If a sit-up was performed incorrectly, the participant was verbally informed of the error, that repetition was not counted, and the participant was allowed to continue immediately.

The 3.2-km runs were conducted on a measured course. The only instruction given to subjects was to complete the run as rapidly as possible. Monitors on the course assured that the subjects completed the entire distance.

Stretcher Carriage - Familiarization

As noted previously, subjects participated in a single-day session (before the experimental sessions) in which they practiced with each stretcher system. Subjects walked for about 5 minutes or until voluntary fatigue was reached with each carriage system, and they used all procedures described in the following experimental carries. The purpose of this session was to familiarize subjects with what to expect during the test trials.

Stretcher Carriage - Experimental Trials

During each of the four stretcher carriage conditions, subjects walked on a motor-driven treadmill set at a pace of 4.8 km/hour, clothed in their physical training (PT) uniform. In all

conditions, they carried an 80-kg manikin on a stretcher. The subjects continued to walk and carry the stretcher until voluntary fatigue or until they had walked 30 minutes. After 30 minutes, the test was terminated by the investigators. Fatigue was indicated by slippage of the stretcher from the hands or voluntary indication on the part of the subject that he or she could not continue any longer. No subject had trouble keeping pace with the treadmill. Time to fatigue (or 30 minutes) served as the performance measure. The 30-minute time limit was selected, based on consultation with subject matter experts (SMEs) who told us that carriages of casualties from remote sites should seldom exceed this time. Further, analysis of distances in Latin America, Korea, and Southwest Asia showed that in 70% of cases, a road or vehicle-accessible trail was available within 2.4 km of any point (Army Development and Employment Agency, 1987). This is the distance covered in 30 minutes at the pace used here.

During all trials, a two-person carry was employed with the subject in the forward position (looking away from the manikin). Only one person walked at a time; the rear portion of the stretcher was supported by straps attached to an overhead frame. The height of the rear stretcher handles was set to closed hand height of the 50th percentile male. This was 77.7 cm, calculated as wrist height minus wrist-to-center-of-grip height (Gordon, et al., 1989). The value was corrected for shoes (2.5 cm) and the height of the treadmill.

Beside the straps attached to the rear handles of the stretcher, straps were also attached to the front handles of the stretcher. The front straps did not support the stretcher (the subject bore the load) but were there only as a safety device if the subject dropped the stretcher. The load mass on the front handles was found to be 45 kg as measured with a Chatillon® (Greensboro, North Carolina) Model CSD200 force gauge. Figure 2 shows the overall setup for the stretcher carriage trials. This was based on the model of Rice et al. (1996b).

While the subject was walking, heart rate, oxygen uptake, ventilation, and a rating of perceived exertion were obtained every minute for the first 5 minutes, at 7.5 minutes, 10 minutes, and every 5 minutes thereafter. Heart rate was determined using a Polar® Heart Rate device (Polar USA, Stamford, Connecticut). The device consisted of a sensor strap and watch. The subject wore the sensor strap around his or her chest and the watch was suspended from the stretcher frame near the subject. The sensor strap contained electrodes, which picked up electrical signals from the heart and transmitted them to the watch. Heart rate was recorded from the watch at the appropriate times.

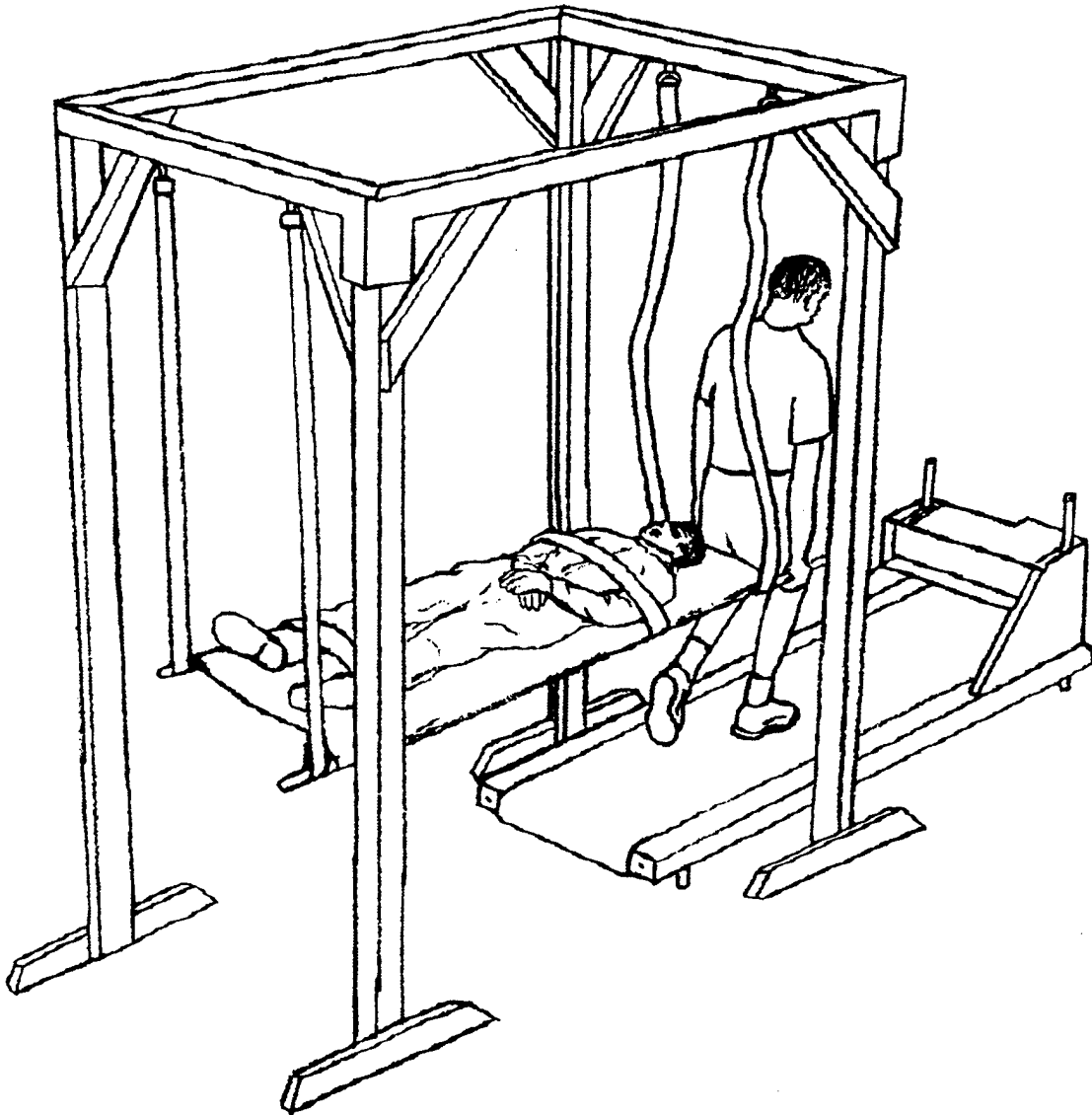


Figure 2. Overall setup for testing the stretcher carriage methods.

The Oxylog2[®] device (PK Morgan, Chatham, United Kingdom) was used to measure oxygen consumption (VO_2) and ventilation (V_E). The subject breathed through a mouth-breathing face mask (Hans Rudolph Inc., Kansas City, Missouri, Series 7970). The face mask was connected to the central Oxylog2[®] unit with Warren Collins[®] (Braintree, Massachusetts) plastic spiral tubing. The subject inhaled room air. The subject's expired gases were passed to the central Oxylog2[®] unit, which contained a Figaro KE-25 oxygen fuel type cell. The PO_2 difference between the inspired and expired gases was measured in the instrument and the extracted volume of oxygen calculated (VO_2). A turbine flow meter was connected to the inlet

valve of the face mask with Warren Collins molded couplers. The turbine was used to calculate the volume of the subjects' inspired air (V_e). Ventilatory equivalent (V_e/VO_2) was also calculated.

The subject was asked to rate the perceived exertion in his or her upper and lower body using the Borg Scale (see Appendix A). This was a 15-point scale with numbers ranging from 6 to 20. Verbal anchors were present at every other number. The scale was designed to quantify the exertion the subject feels during exercise, and higher numbers are associated with higher perceived exertion (Borg, 1970).

Before and immediately after the treadmill walk, the subject's right and left hand grip strength was tested. Two trials were obtained with each hand using the same procedures employed in the pre-test. If the two trials were not within 10% of each other, a third trial was conducted and the two highest averaged. Right and left hands were alternated so that one was used in the first trial, the other hand in the second trial, the first hand in the third trial, and so on. The starting hand (right or left) was also alternated among subjects.

After the subjects had completed the hand grip test and removed the harnesses and test equipment, they completed a pain, soreness, and discomfort questionnaire (see Appendix B) (Knapik, et al., 1990). Subjects were asked to rate any pain, soreness, or discomfort that they were currently feeling in any of 11 body parts. Both the anterior and posterior parts of the body were rated on a six-point Likert scale ranging from 1 ("none") to 6 ("extreme"). Verbal anchors were present at each of the six rating points.

Post-Study Questionnaires

After performing all four stretcher carriage trials, the subjects completed a stretcher utility questionnaire (see Appendix C) and a paired comparison questionnaire. The stretcher utility questionnaire consisted of several questions that asked subjects to rate each carriage system for comfort, ease of use, ease of carrying, overall stability, usefulness in the field, and effort required. For each question, there was a seven-point Likert scale with verbal anchors at three points.

The paired comparison questionnaire (see Appendix D) contained six pages, each containing two stretcher carriage methods. The subject was instructed to circle one choice, move to the next page, and not to return to a previous page.

RESULTS

Stretcher Carriage Times

It was not possible to use hypothesis testing statistics on the performance times because we stopped subjects at 30 minutes of carrying. This artificially truncated times and may violate the assumption of linearity in analysis of variance (ANOVA). The use of non-parametric statistics may also be precluded because the subjects who were able to continue for 30 minutes had the same relative ranking. Thus, we chose only to show the individual values and descriptive statistics. Table 1 shows these for the four experimental conditions.

With hand carriage, no subject was able to continue carrying the stretcher longer than 6.4 minutes. In the cross-shoulder condition, two subjects were able to complete 30 minutes. With the hip-shoulder and LCE methods, eight and six subjects, respectively, completed 30 minutes.

Cardiorespiratory and Rating of Perceived Exertion (RPE) Measures During Treadmill Walks

Measures obtained during the treadmill walks (heart rate, VO_2 , V_e , V_e/VO_2 , and RPE) were analyzed using a one-way repeated measures ANOVA comparing the four stretcher carriage methods at each time point. When significant differences were found, the Tukey Honestly Significant Difference (HSD) Test was used to identify differences between methods. Subjects were compared at each time point (rather than over the entire test) because individual subjects fatigued at different times. An analysis at each time point allows for inclusion of the greatest number of subjects (in a repeated measures design only complete data can be used). The number of subjects used at each point in the ANOVA is shown in each table.

Comparisons between all carriage systems could only be made as long as 2 minutes because by Minute 3, only three subjects remained in the hand carriage group. For Minutes 3 to 15, comparisons were made among the three remaining systems. By Minute 20, only two subjects were able to continue with the cross-shoulder method so the analysis from Minutes 20 to 30 included only the hip-shoulder and LCE systems.

Graphs depicting the descriptive cardiorespiratory and RPE values have a different number of subjects than the ANOVAs. The graphs use data from all available subjects at each time point and each carriage system. The number of subjects at each time point for each carriage system (i.e., the number of subjects at each time point in the graphs) is shown in Table 2.

Figure 3 shows the heart rate data and Table 3 summarizes the statistical analysis. It can be seen that during hand carriage, heart rate generally rose until fatigue. The slight drop at Minute

2 is attributable to three subjects who were not included at this point who had very high heart rates at Minute 1 and quit before Minute 2. During the other three carriage conditions, heart rate rose initially then stabilized after 3 to 4 minutes. Hand carriage resulted in higher heart rates at Minutes 1 and 2, but there were no significant differences between the other three carriage methods at any time.

Table 1
Individual Data and Group Descriptive Statistics
for Stretcher Carriage Times (minutes)

Subject No. or group	Gender	Hand (min)	Cross shoulder (min)	Hip- shoulder (min)	LCE integrated (min)
1	Man	2.5	10.2	30.0	8.5
2	Man	4.3	30.0	30.0	30.0
3	Man	2.9	30.0	30.0	30.0
4	Man	6.4	10.3	30.0	30.0
5	Man	1.8	15.3	30.0	30.0
6	Man	2.1	12.3	30.0	30.0
7	Man	2.3	17.1	30.0	16.1
8	Woman	1.8	5.6	30.0	30.0
9	Woman	2.3	9.7	8.3	9.7
10	Woman	2.0	10.9	14.3	8.8
11	Woman	1.4	8.1	16.5	15.1
Group (n=11)	M	2.7	14.5	25.4	21.7
	SD	1.4	8.3	8.1	9.9
Men (n=7)	M	3.2	17.9	30.0	24.9
	SD	1.6	8.6	0	8.9
Women (n=4)	M	1.9	8.6	17.3	15.9
	SD	0.4	2.3	9.2	9.8

Table 2

Number of Subjects at Each Time Point During the Stretcher Carriage Conditions
(these are the number of subjects used in graphing the cardiorespiratory data)

Time (min)	Hand (n)	Cross-shoulder (n)	Hip-shoulder (n)	LCE integrated (n)
1	11	11	11	11
2	8	11	11	11
3	3	11	11	11
4	2	11	11	11
5	1	11	11	11
7.5	0	10	11	11
10	0	6	11	10
15	0	4	9	10
20	0	2	8	6
25	0	2	8	6
30	0	2	8	6

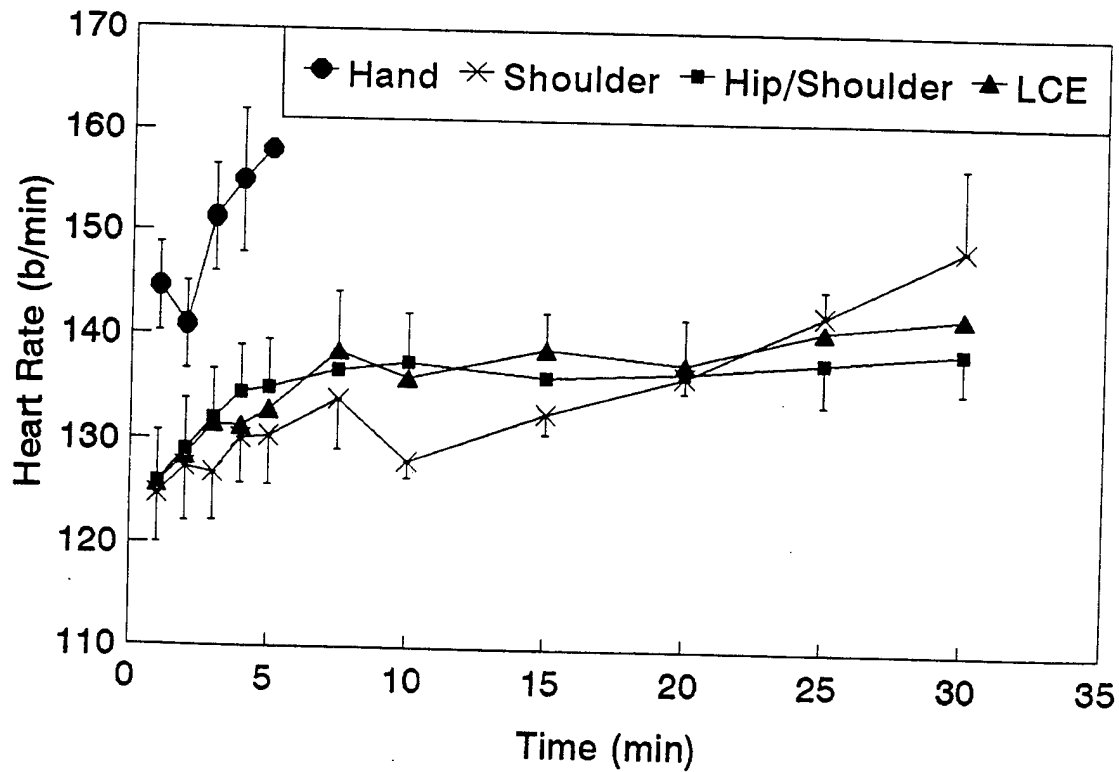


Figure 3. Heart rate during walking with four methods of stretcher carriage.

Table 3
Heart Rate Data Comparing Stretcher Carriage Methods

Minute	N	Comparison ^a	F-value	p-value	Tukey HSD Test results ^a
1	11	H,CS,HS,LCE	19.10	<0.001	H>CS,HS,LCE ($p<0.01$)
2	8	H,CS,HS,LCE	4.46	0.014	H>CS,HS,LCE ($p<0.01$)
3	11	CS,HS,LCE	1.86	0.182	
4	11	CS,HS,LCE	1.23	0.314	
5	11	CS,HS,LCE	1.22	0.317	
7.5	10	CS,HS,LCE	0.86	0.440	
10	6	CS,HS,LCE	0.19	0.832	
15	4	CS,HS,LCE	0.07	0.937	
20	6	HS,LCE	0.03	0.876	
25	6	HS,LCE	0.75	0.425	
30	6	HS,LCE	0.86	0.395	

^aH = hand; CS = cross shoulder; HS = hip-shoulder; LCE = load carriage equipment integrated

Figure 4 depicts the oxygen consumption (VO_2) data and Table 4 summarizes the statistical comparison. The cross-shoulder condition resulted in slightly lower energy cost than the LCE integrated condition at Minutes 2 and 5. The cross-shoulder method also had lower energy cost than the hip-shoulder method at Minute 5. The hip-shoulder method had slightly lower energy cost than the LCE method at 20 minutes.

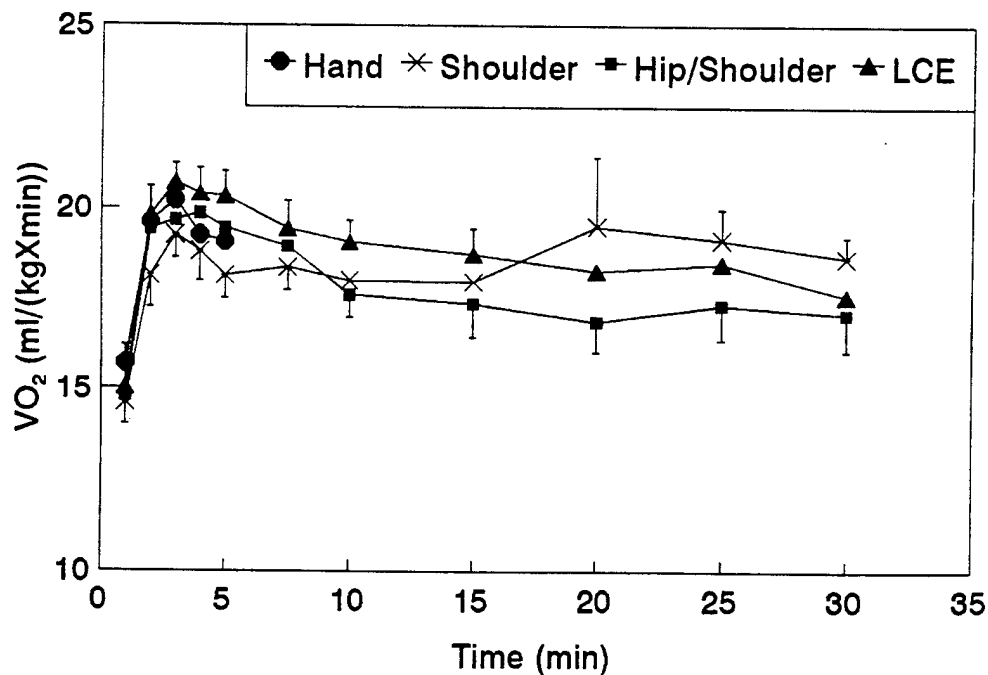


Figure 4. Oxygen consumption during walking with four methods of stretcher carriage.

Table 4
Oxygen Consumption (VO_2) Data Comparing Stretcher Carriage Methods

Minute	N	Comparison	F-value	p-value	Tukey HSD Test results
1	11	H,CS,HS,LCE	1.45	0.247	
2	8	H,CS,HS,LCE	4.45	0.017	CS<LCE ($p<0.05$)
3	11	CS,HS,LCE	1.95	0.168	
4	11	CS,HS,LCE	1.75	0.200	
5	11	CS,HS,LCE	3.94	0.036	CS<HS, LCE($p<0.05$)
7.5	10	CS,HS,LCE	1.57	0.234	
10	6	CS,HS,LCE	2.38	0.134	
15	4	CS,HS,LCE	0.46	0.652	
20	6	HS,LCE	3.53	0.017	HS<LCE ($p<0.01$)
25	6	HS,LCE	1.60	0.169	
30	6	HS,LCE	0.59	0.466	

Figure 5 shows the minute ventilation data (V_e) and Table 5 summarizes the statistical comparison. Ventilation rose progressively in the hand carriage condition. Hand carriage resulted in higher ventilation than did any of the other carriage methods at Minutes 1 and 2; there were no significant differences among the other carriage methods at these times. The cross-shoulder method resulted in lower ventilation than did the LCE integrated method at Minute 5, and this same trend was still apparent at Minute 7.5.

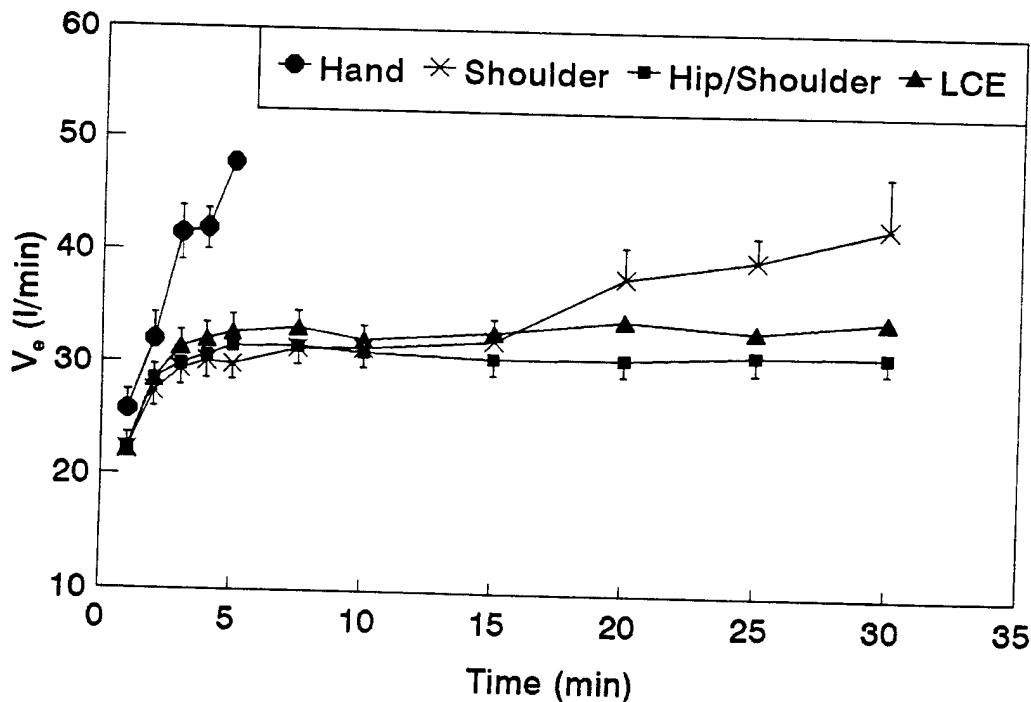


Figure 5. Ventilation during walking with four methods of stretcher carriage.

Table 5

Minute Ventilation (V_e) Data Comparing Stretcher Carriage Methods

Minute	N	Comparison	F-value	p-value	Tukey HSD Test results
1	11	H,CS,HS,LCE	3.91	0.018	H>CS,HS,LCE ($p<0.05$)
2	8	H,CS,HS,LCE	4.36	0.016	H>CS,HS,LCE ($p<0.01$)
3	11	CS,HS,LCE	1.81	0.189	
4	11	CS,HS,LCE	2.19	0.139	
5	11	CS,HS,LCE	3.61	0.046	CS>LCE ($p<0.05$)
7.5	10	CS,HS,LCE	2.82	0.086	
10	6	CS,HS,LCE	0.20	0.824	
15	4	CS,HS,LCE	0.24	0.797	
20	6	HS,LCE	2.34	0.187	
25	6	HS,LCE	0.53	0.498	
30	6	HS,LCE	1.00	0.364	

Figure 6 shows the ventilatory equivalent data (V_e/VO_2) and Table 6 summarizes the statistical comparison. At Minute 1, hand carriage resulted in a slightly higher value, and by Minute 2, this was statistically significant. There were no statistically significant differences between methods at any other time point.

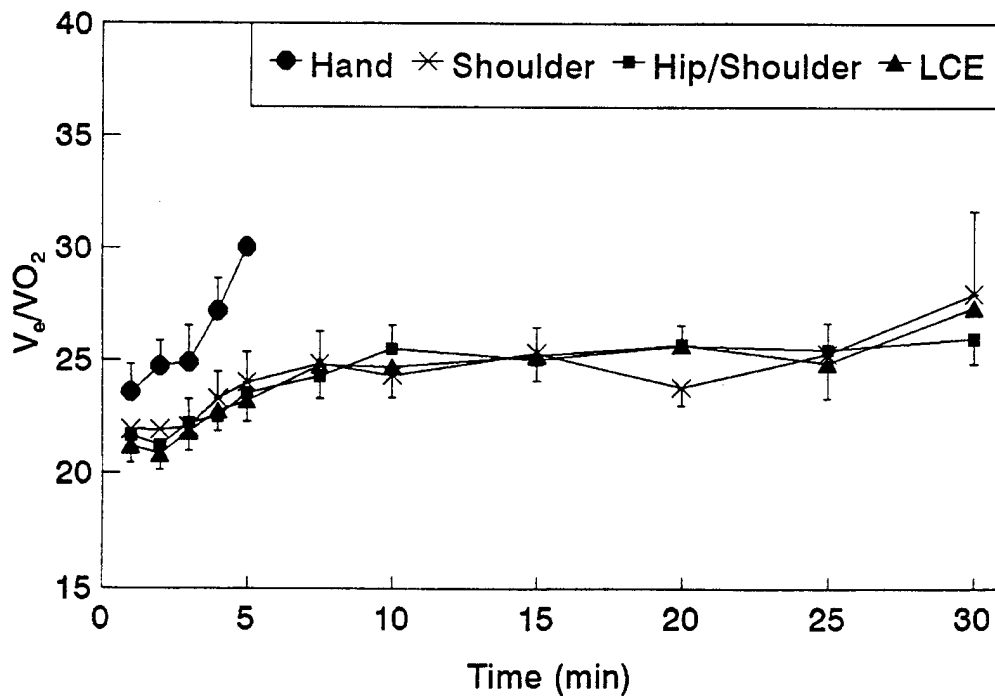


Figure 6. Ventilatory equivalent during walking with four methods of stretcher carriage.

Table 6

Ventilatory Equivalent (V_e/VO_2) Data Comparing Stretcher Carriage Methods

Minute	N	Comparison	F-value	p-value	Tukey HSD Test results
1	11	H,CS,HS,LCE	2.69	0.064	H>CS,HS,LCE ($p<0.05$)
2	8	H,CS,HS,LCE	4.46	0.017	
3	11	CS,HS,LCE	0.15	0.858	
4	11	CS,HS,LCE	0.62	0.546	
5	11	CS,HS,LCE	0.33	0.720	
7.5	10	CS,HS,LCE	0.46	0.637	
10	6	CS,HS,LCE	0.27	0.767	
15	4	CS,HS,LCE	0.30	0.751	
20	6	HS,LCE	0.04	0.852	
25	6	HS,LCE	0.31	0.602	
30	6	HS,LCE	0.09	0.777	

Figure 7 shows the upper body RPE data and Table 7 summarizes the statistical comparison. Hand carriage resulted in higher RPE values than any other carriage method. This was statistically significant when it could be compared to the other forms of carriage, during the first 2 minutes. All other forms of carriage tended to increase with time but not as steeply as hand carriage. Cross-shoulder carriage resulted in higher upper body perceived exertion than the hip-shoulder or LCE integrated methods through Minute 10. From 20 to 30 minutes, upper body RPE was significantly lower for the LCE method than for the hip-shoulder method.

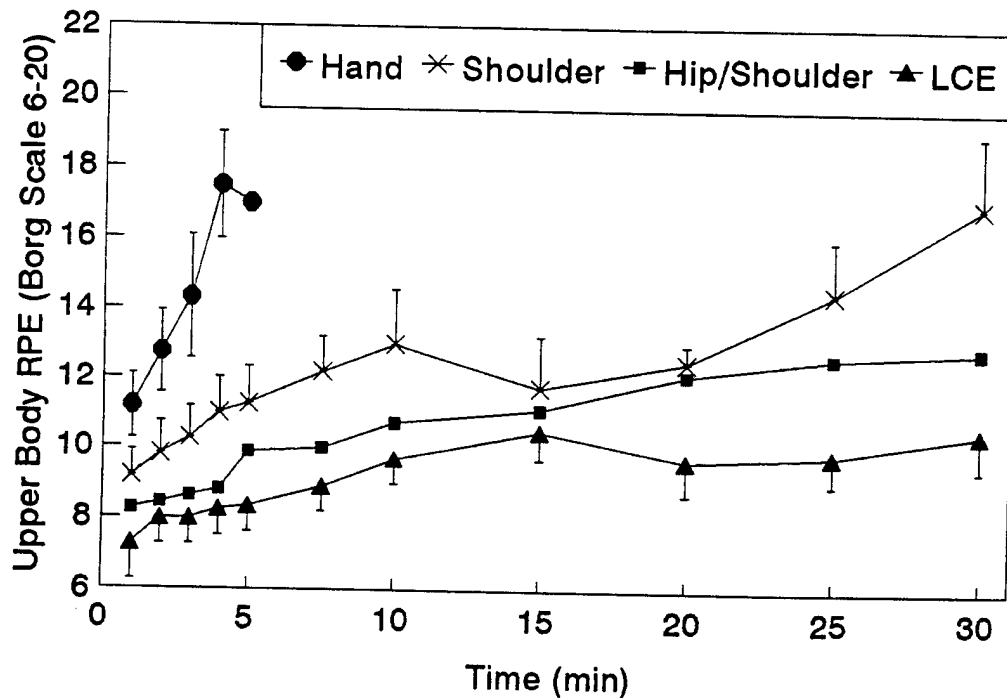


Figure 7. Upper body RPE during walking with four methods of stretcher carriage.

Table 7

Upper Body RPE Data Comparing Stretcher Carriage Methods

Minute	N	Comparison	F-value	p-value	Tukey HSD Test results
1	11	H,CS,HS,LCE	10.49	<0.001	H>CS($p<0.05$); H>HS,LCE($p<0.01$)
2	8	H,CS,HS,LCE	13.51	<0.001	H>CS,HS,LCE ($p<0.01$)
3	11	CS,HS,LCE	9.14	0.002	CS>HS ($p<0.05$); CS>LCS($p<0.01$)
4	11	CS,HS,LCE	10.07	0.001	CS>HS,LCE ($p<0.01$)
5	11	CS,HS,LCE	10.60	0.001	CS>HS,LCE ($p<0.01$)
7.5	10	CS,HS,LCE	5.77	0.012	CS>HS,LCE ($p<0.05$)
10	6	CS,HS,LCE	6.31	0.013	CS>HS ($p<0.05$); CS>LCS($p<0.01$)
15	4	CS,HS,LCE	0.80	0.510	
20	6	HS,LCE	7.48	0.041	HS>LCE ($p<0.05$)
25	6	HS,LCE	12.31	0.017	HS>LCE ($p<0.05$)
30	6	HS,LCE	7.66	0.040	HS>LCE ($p<0.05$)

Figure 8 shows the lower body RPE data and Table 8 summarizes the statistical comparison. There were no significant differences between methods until Minute 4 when the LCE method resulted in higher perceived exertion than the cross-shoulder method. This difference was maintained through Minute 10.

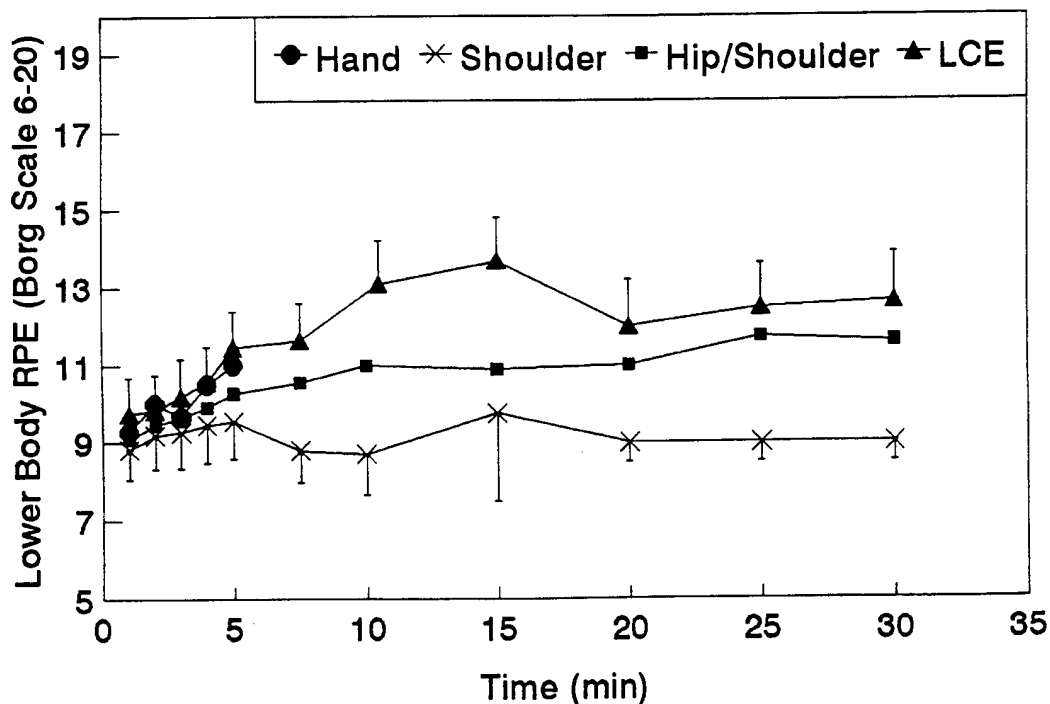


Figure 8. Lower body RPE during walking with four methods of stretcher carriage.

Table 8
Lower Body RPE Data Comparing Stretcher Carriage Methods

Minute	N	Comparison	F-value	p-value	Tukey HSD Test results
1	11	H,CS,HS,LCE	0.98	0.415	
2	8	H,CS,HS,LCE	3.02	0.053	
3	11	CS,HS,LCE	1.72	0.204	
4	11	CS,HS,LCE	3.66	0.044	LCE>CS ($p<0.05$)
5	11	CS,HS,LCE	7.41	0.004	LCE>CS ($p<0.05$)
7.5	10	CS,HS,LCE	8.65	0.002	LCE>CS ($p<0.01$); HS>CS ($p<0.05$)
10	6	CS,HS,LCE	13.16	<0.001	LCE>CS($p<0.01$); LCE>HS ($p<0.01$)
15	4	CS,HS,LCE	4.78	0.057	
20	6	HS,LCE	2.29	0.191	
25	6	HS,LCE	2.29	0.191	
30	6	HS,LCE	2.76	0.158	

Hand Grip Strength Before and After Stretcher Carriage

Hand grip data were analyzed using a three-way repeated measures ANOVA comparing the four stretcher carriage methods, the right and left hands, and the pre and post treadmill values (4 x 2 x 2 analysis). When significant differences were found, the Tukey HSD Test was used to isolate differences between factors.

Figure 9 shows the hand grip data. There were significant main effects for carriage methods ($p<0.001$), right-left hands ($p=0.007$), and pre-post treadmill ($p=0.001$). There was a significant Method x Pre-post interaction ($p<0.001$), but neither the Method x Right-left ($p=0.441$) nor Pre-post x Right-left ($p=0.111$) interaction was significant. The three-way interaction was significant ($p=0.008$). Post hoc analysis indicated that following hand carriage, there were significant declines in grip strength on both the right and left side ($p<0.01$); the absolute decline on the left side was more than twice as great as that on the right side (45 versus 21 kg). Following cross-shoulder carriage, there was a significant decline in grip strength on the right side ($p<0.01$) but not the left side. No other carriage method demonstrated significant changes in post-exercise grip strength ($p>0.05$).

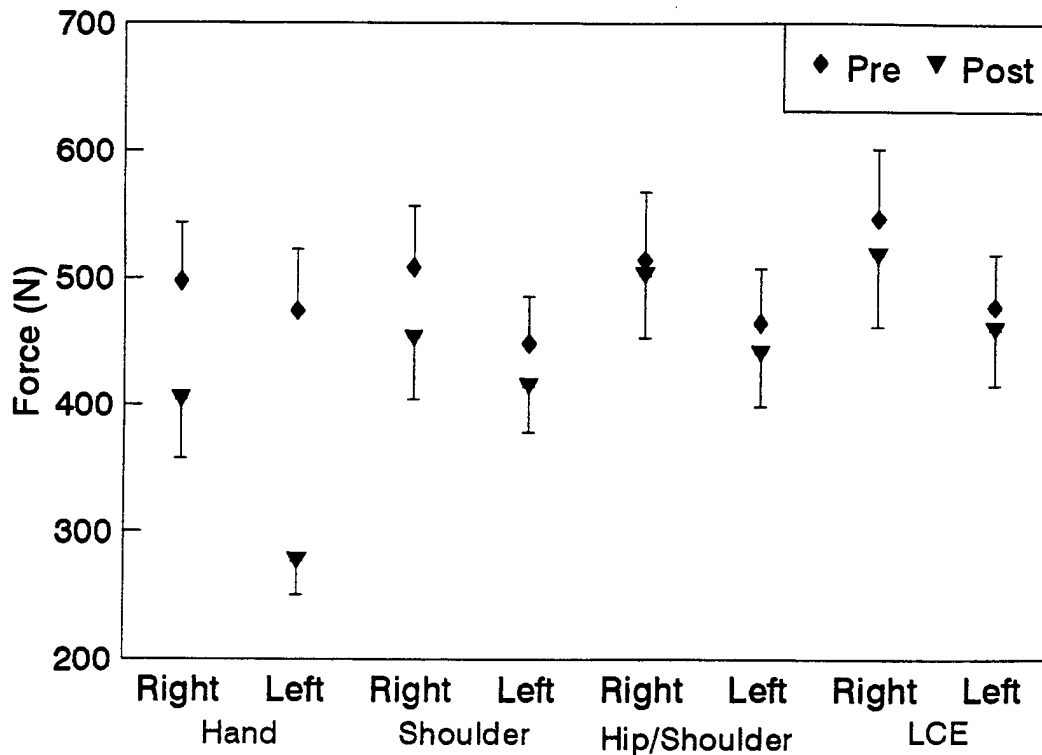


Figure 9. Hand grip strength before and after walking with four methods of stretcher carriage (mean \pm SE).

Post-Exercise Ratings of Pain, Soreness, and Discomfort

PSD ratings were analyzed using the Friedman Test for related samples. The four stretcher carriage methods were compared at each body part. When significant differences were obtained, partitioned Friedman Tests were used in order to determine differences between methods.

Figures 10 and 11 show the PSD ratings for the anterior and posterior aspects of the body, respectively. Tables 9 and 10 contain the statistical analysis for the anterior and posterior aspects of the body, respectively. Hand carriage resulted in higher PSD than the other three methods in the hands, forearms, and posterior upper arms. The cross-shoulder method resulted in higher PSD in the neck, posterior shoulders, upper chest, and upper back, compared to most other methods. The LCE and hip-shoulder methods were similar, resulting in more PSD in the hip and abdomen, buttocks, thighs, and anterior lower leg when compared to most other carriage methods. The hip-shoulder method tended to cause more PSD in the posterior shoulders, compared to hand and LCE carriage. LCE carriage resulted in higher PSD in the hip and abdomen area, compared to all other forms of carriage.

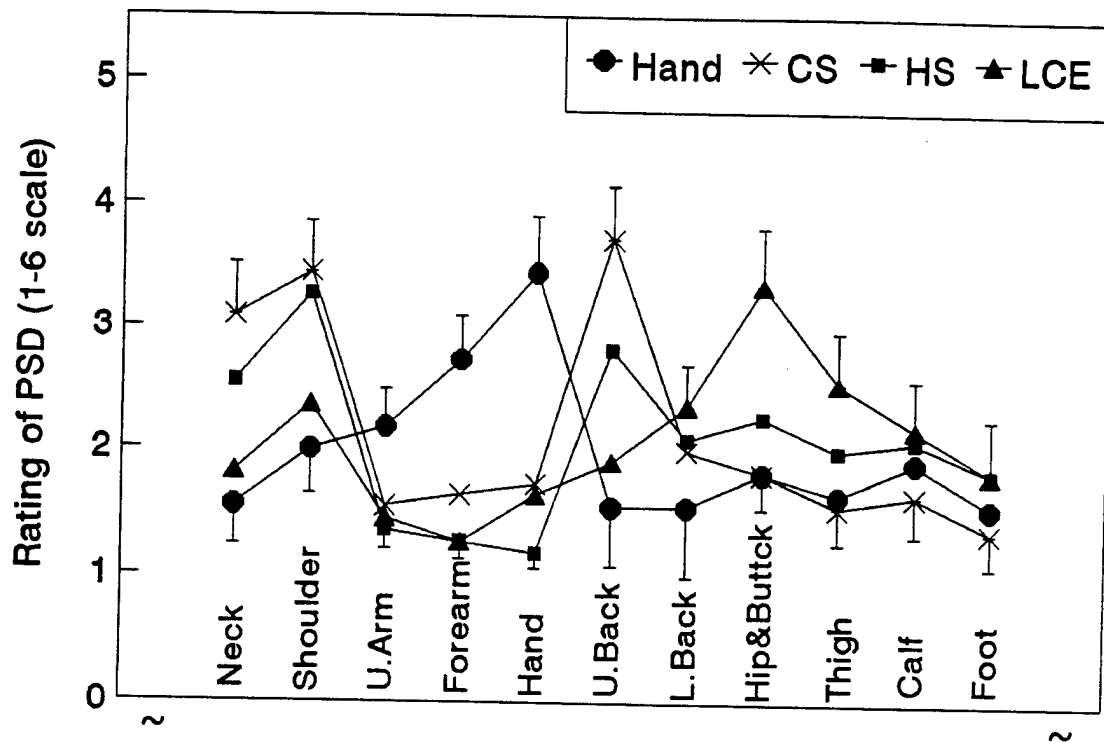


Figure 10. PSD ratings (posterior) after walking with four methods of stretcher carriage.

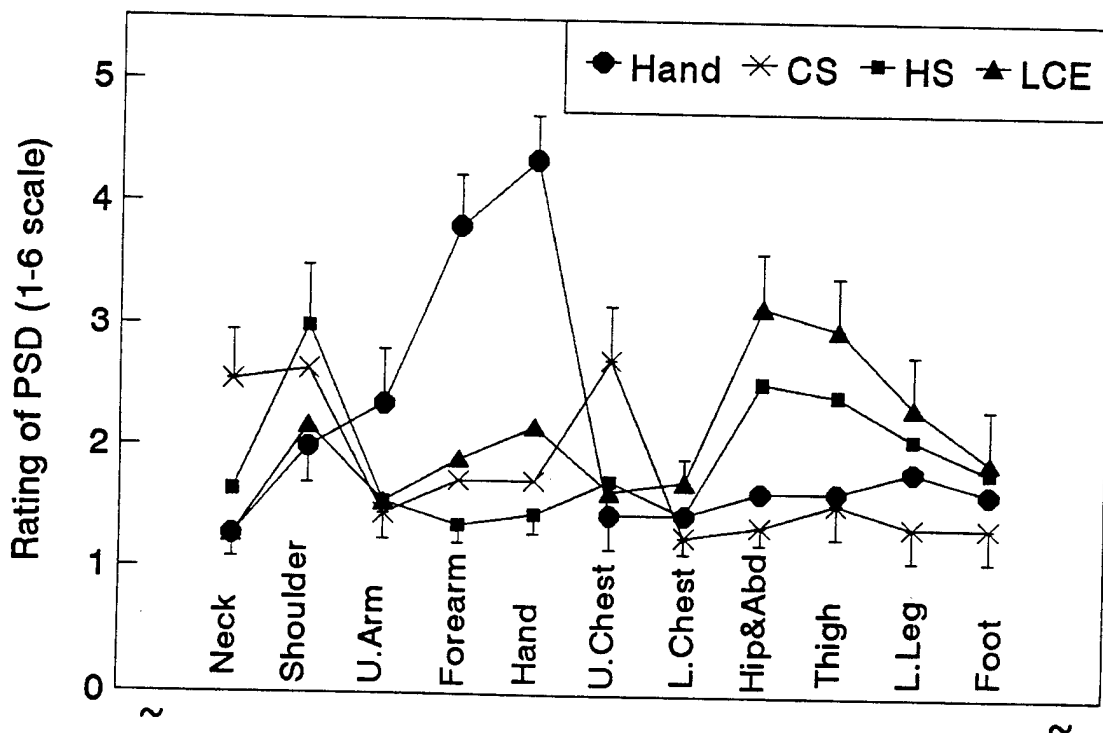


Figure 11. PSD ratings (anterior) after walking with four methods of stretcher carriage.

Table 9
PSD Data (anterior aspect of body) After the Treadmill
Walk Comparing Stretcher Carriage Methods

Body part	Chi-square value (Friedman Test)	p-value	Partitioned Friedman Test results (numbers in parentheses are exact probabilities)
Neck	11.08	0.011	CS>H(.020),HS(.001),LCE(.020)
Shoulder	4.71	0.195	
Upper arm	4.25	0.236	
Forearm	23.88	<0.001	H>CS(.003),HS(.001),LCE(.003); LCE>HS(.046)
Hand	23.17	<0.001	H>CS(.002),HS(.008),LCE(.002)
Upper chest	10.21	0.017	CS>H(.034),HS(.008),LCE(.059)
Lower chest	4.32	0.229	
Hip and abdomen	15.53	0.001	LCE>H(.034), CS(.003), HS(.096); HS>H(.034),CS(.014)
Thigh	16.31	0.001	LCE>H(.020),CS(.005); HS>H(.008),CS(.008)
Lower leg	10.99	0.012	CS<H(.025),HS(.008),LCE(.008)
Foot	5.609	0.132	

Table 10
PSD Data (posterior aspect of body) After the Treadmill
Walk Comparing Stretcher Carriage Methods

Body part	Chi-square value (Friedman Test)	p-value	Partitioned Friedman Test results (numbers in parentheses are exact probabilities)
Neck	9.716	0.021	CS>H(.011),LCE(.034)
Shoulder	12.48	0.006	CS>H(.011),LCE(.059); HS>H(.008),LCE(.034)
Upper arm	6.848	0.077	H>CS(.103),HS(.046),LCE(.046)
Forearm	16.13	0.001	H>CS(.005),HS(.034),LCE(.005)
Hand	14.40	0.002	H>CS(.058),HS(.003),LCE(.020)
Upper back	23.50	<0.001	CS>H(.003),HS(.014),LCE(.002); HS>H(.005),LCE(.008); LCE>H(.103)
Lower back	7.61	0.055	LCE>H(.008); HS>H(.025)
Hip and buttocks	15.85	0.001	LCE>H(.020),CS(.005),HS(.008); HS>H(.103),CS(.103)
Thigh	12.12	0.007	LCE>H(.025),CS(.008); HS>H(.083),CS(.083)
Calf	4.16	0.245	
Foot	5.15	0.161	

Body parts were combined on the PSD questionnaire in order to determine broad body areas where the subjects reported PSD. Areas combined were those where the particular stretcher carry methods would be expected to stress particular areas of the body, based on observation, experience, and pilot studies. The specific body parts from the PSD questionnaire (see Appendix B) that were combined and averaged were as follow: Parts 1, 2, and 6, averaged to form a "Shoulder and Upper Trunk Score"; Parts 3, 4, and 5, averaged to form the "Arm and Hand Score"; Parts 7 and 8, averaged to form the "Hip and Lower Trunk Score"; Parts 9, 10, and 11, averaged to form the "Leg and Feet Score."

For the combined body parts, Figure 12 shows the average values and Table 11 shows the statistical analysis. Following hand carriage, the arms and hands had the highest PSD and there was little PSD elsewhere. Following cross-shoulder carriage, the shoulders and upper trunk had the highest PSD and there was little PSD in the areas below the chest. Following hip-shoulder and LCE carriage, the hips and lower trunk, as well as the legs and feet had the highest. However, the LCE method did not result in much PSD in the shoulder and upper trunk area.

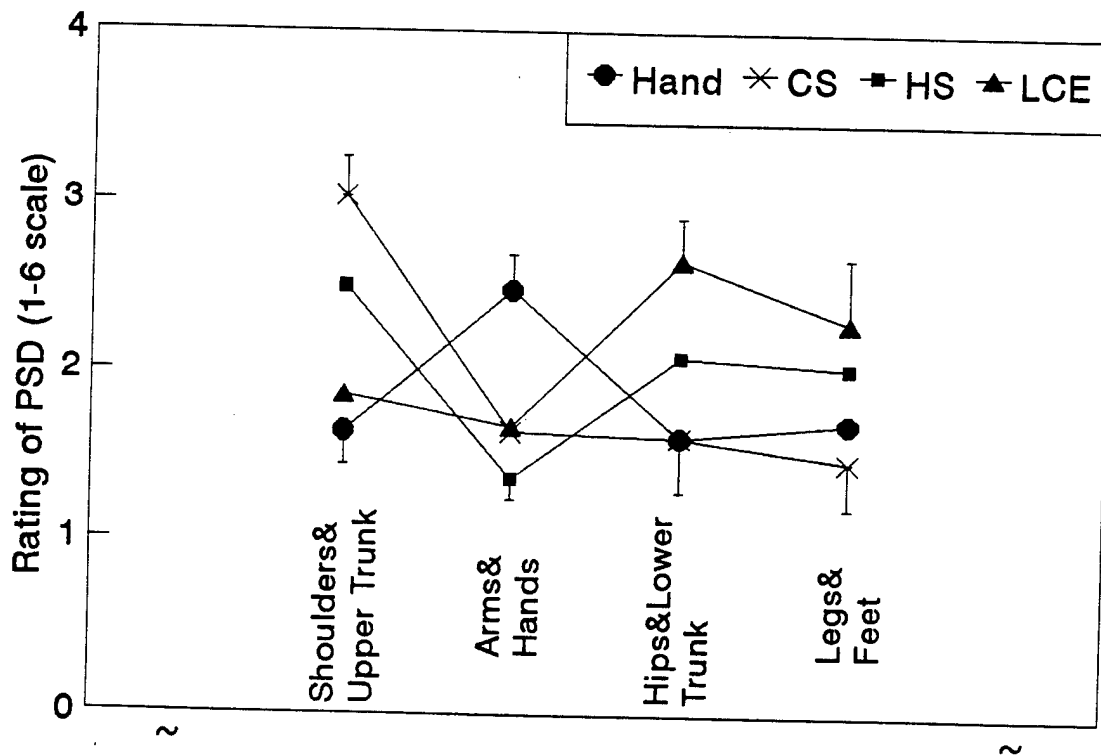


Figure 12. Combined PSD ratings after walking with four methods of stretcher carriage.

Table 11

Pain, Soreness, and Discomfort Data
(combining body parts) After the Treadmill Walk

Body areas ^a	Chi-square value (Friedman Test)	p-value	Partitioned Friedman Test results (numbers in parentheses are exact probabilities)
Shoulders and upper trunk (Parts 1,2,6)	18.72	<0.001	CS>H (.001), LCE(.003); HS>H(.001)
Arms and hands (Parts 3,4,5)	18.24	<0.001	H>CS(.007), HS(.001),LCE(.003)
Hips and lower trunk (Parts 7,8)	14.94	0.002	HS>H(.020),CS(.034); LCE>H(.058),CS(.002),HS(.100)
Legs and feet (Parts 9,10,11)	12.51	0.006	HS>H(.096),CS(.008); LCE>H(.016),CS(.003)

^aPart numbers refer to numbers on PSD questionnaire (see Appendix B)

Responses to Utility Questionnaire Upon Completion of Stretcher Carriage Trials

Responses to the utility questionnaire were analyzed using the Friedman Test for related samples. For each of the six questions, initial comparisons were made among the four stretcher carriage conditions. When significant differences were found, partitioned Friedman Tests were conducted to determine differences between groups.

Figure 13 shows the utility questionnaire responses and Table 12 summarizes the statistical analysis. Subjects' responses on the hip-shoulder and LCE methods were significantly more favorable than responses on the hand and cross-shoulder methods. There were no differences in the responses between the hip-shoulder and LCE methods.

On all six questions, hand carriage was rated significantly less favorable than all the other methods. One exception was "usefulness in the field" where differences between the hand and cross-shoulder carriage were marginal.

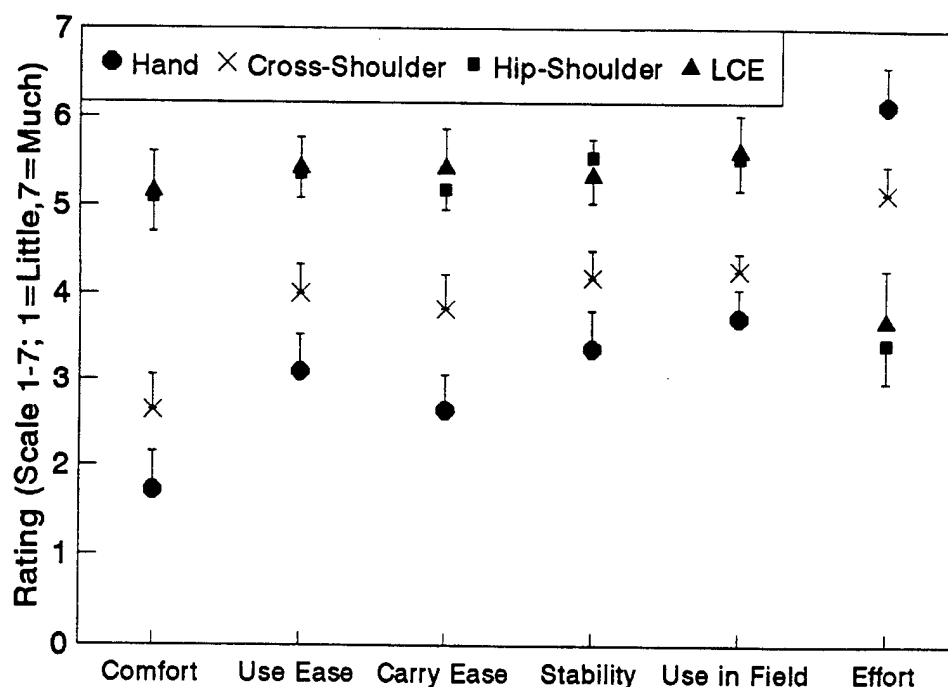


Figure 13. Utility questionnaire responses after completing exercise with all four stretcher carriage methods.

Table 12
Responses to the Utility Questionnaire After Completing
Exercise With all Four Stretcher Carriage Methods

Question	Chi-square value (Friedman Test)	p-value	Partitioned Friedman Test results (numbers in parentheses are exact probabilities)
Comfort	20.35	<0.001	LCE>H(.003),CS(.002); HS>H(.003),CS(.007); CS>H(.011)
Ease of use	16.85	<0.001	LCE>H(.005),CS(.008); HS>H(.003),CS(.058); CS>H(.059)
Ease of carry	19.9	<0.001	LCE>H(.003),CS(.020); HS>H(.003),CS(.020); CS>H(.008)
Overall stability	16.53	<0.001	LCE>H(.003),CS(.059); HS>H(.011),CS(.059); CS>H(.034)
Usefulness in field	15.13	.002	LCE>H(.001),CS(.034); HS>H(.035),CS(.020); CS>H(.180)
Effort required	9.56	.023	LCE<H(.103),CS(.014); HS<H(.007),CS(.011); CS<H(.020)

Responses to Paired Comparison Questionnaire Upon Completion of Stretcher Carriage Trials

The paired comparison questionnaire was analyzed using the methods of Maxwell (1974) in which an incidence matrix is produced and Z-score transformations are created to show the relative preferences of subjects for the different choices. Table 13 shows the incidence matrix indicating the number of subjects selecting one stretcher carriage method over another. Figure 14 shows the scaled object distances, indicating the relative preference for each form of stretcher carriage. The exact scaled indices were -2.08 for hand carriage, -1.42 for cross-shoulder, 1.66 for LCE, and 1.84 for the hip-shoulder. It is clear that the LCE and hip-shoulder methods were preferred to the hand and cross-shoulder techniques by a large margin.

Table 13
Paired Comparison Questionnaire Incidence Matrix

	Number of subjects selecting the system in the column instead of the system in the row			
	Hand	Cross-shoulder	Hip-shoulder	LCE
Hand	-	10	11	11
Cross-Shoulder		-	11	11
Hip-Shoulder			-	4
LCE				-

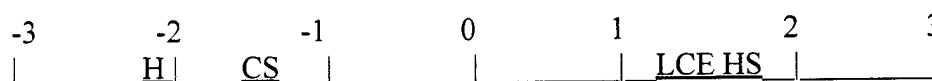


Figure 14. Scaled indices for the stretcher carriage methods.

Pre-Test Measures

Pre-test measures were obtained in order to characterize subjects relative to other Army samples and to look at relationships between these variables and hand carriage times. Appendix E contains the descriptive statistics. Table E-1 shows basic physical characteristics, including age, anthropometry, and body composition. Table E-2 displays the strength and APFT measures. Table E-3 displays the cross-sectional muscle or bone and muscle areas for the upper arm, forearm, and thigh.

Factors Accounting for Hand Carriage Performance

To determine factors that may account for some of the variance in hand carriage performance, forward stepwise multiple linear regression was used. The dependent variable was hand carriage performance times and independent variables were all those shown in Appendix E except for total APFT points. These included the anthropometric measures, body composition (body fat and fat-free body mass), muscle strength (pre-test hand grip, squat, bench press), and APFT scores (push-ups, sit-ups, 3.2-km run) and the estimates of muscle and bone and muscle cross-sectional area. The other stretcher carriage methods were not considered because times were truncated at 30 minutes and do not represent the maximal physical capability of the subjects. Truncation of performance times results in "grouping of scores" and violates the assumption of linearity in linear regression (Chatterjee & Price, 1991).

The stepwise multiple linear regression procedure showed that three variables (forearm bone and muscle mass, estimated thigh muscle mass, and push-ups) accounted for 99% of the variance in hand carriage times ($F=127.62$, $p<0.001$) with a standard error of estimate of 0.22 minute. Table 14 shows the regression coefficients, confidence intervals, and multiple R-value at each step of the procedure.

Table 14
Regression Coefficients, Confidence Intervals, and Multiple R-Value

Variable	β	β 95% confidence interval	R-value with previous factor(s) in equation
(Constant)	-1.802	-3.011 to -0.594	-
Forearm muscle and bone area	0.206	0.173 to 0.240	0.862
Thigh muscle area	-0.029	-0.038 to -0.020	0.982
Push-ups	-0.020	-0.037 to -0.002	0.994

DISCUSSION

General Findings

This study demonstrates that stretcher carriage methods that displace the load mass from the hands and forearms and move that mass to the shoulders or hips result in longer performance times and are preferred by subjects. The cross-shoulder, hip-shoulder, and LCE integrated methods extended performance times (relative to hand carriage) by 537%, 941%, and 804%, respectively. These are underestimates of the actual performance improvements because if the subject was able to continue for 30 minutes, we stopped the test.

These results confirm many of the findings of Lind and McNicol (1968) and Rice and coworkers (Rice, 1992; Rice, et al., 1996a), showing that loads placed on the shoulders improve performance times. Our results extend these previous findings, suggesting that loads placed on the hips or on the hips and shoulders may have advantages over shoulder-only carriage. The hip-shoulder and LCE systems resulted in longer carriage times and were preferred by subjects to the cross-shoulder method. The cross-shoulder method placed the load exclusively on a small part of the shoulders; there was little opportunity to move the load to another location on the shoulder. Lifting the stretcher with the hands could relieve the shoulders for a short period of time, but when the load was placed back on the shoulders, it was invariably in the same place where it had been previously. In contrast, the hip-shoulder method and, to some extent, the LCE method, also allowed large portions of the load to be carried on both the hips and shoulders. This distributed the mass over a larger area of the body and possibly minimized localized cutaneous pressure.

The hip-shoulder method resulted in somewhat longer performance times than the LCE method. Although we could not perform statistical analysis on the carriage times for reasons already mentioned, more subjects reached the 30-minute limit with the hip-shoulder method than with the LCE method (eight versus six); in all but one case, those who did not reach 30 minutes had longer performance times with the hip-shoulder method. This suggests a slight advantage for the hip-shoulder method. This may have been attributable to the more effective ability to shift loads with this method. The hip-shoulder harness was designed to allow the load mass to be carried on the hips or the shoulders or partly on each. Load shifting may have allowed the load pressure to be shifted from one body location to another, allowing a return of peripheral circulation to cutaneous areas where the load was previously placed. In addition, load shifting could have allowed formerly loaded muscle groups to replenish local energy substrates (Ahlborg & Felig, 1982) when the load was shifted to other muscle groups.

Despite the fact that the hip-shoulder method may have had a slight performance advantage over the LCE method, both systems were equally preferred by subjects for comfort, ease of use, ease of carry, stability, and usefulness in the field. The LCE method also has the advantage of fitting into existing Army load carrying equipment, providing a powerful practical benefit over the hip-shoulder method. By taking a relatively light piece of equipment to the field and attaching it to equipment the soldier is already wearing, stretcher carriage time can be increased substantially. However, further developmental work is still required on this system because the device we developed caused thigh abrasions in at least two cases. This was because of downward and inward force exerted on the clip by the weight of the stretcher. This forced the ends of the clips into the subjects' thighs. As subjects walked, the continued rubbing of the thighs on these clip ends caused the abrasions. It may be possible to improve the system by providing a broader plastic clip and minimize mass on the lower portion of the clip. Providing appropriate padding on the lower part of the system may also help.

One major problem with both the hip-shoulder and LCE systems was that the fabric loops that held the stretcher handles did not allow easy entry or exit of these handles. In fact, for this study, investigators placed the stretcher handles into and removed them from the loops. This was because our main interest was in performance time and we wanted to prevent the subjects from stumbling on the moving treadmill. During consultation visits with SMEs after the data collection, we were told that the loops may not be desirable because if the carrier fell, he or she could be injured. A possible alternative is to use open aluminum hooks (similar to those on the cross-shoulder system) rather than fabric loops. This would allow for more rapid entry and exit for the stretcher handles.

Ratings of Pain, Soreness, and Discomfort (PSD)

Different carriage methods resulted in PSD in different parts of the body. Most striking was the fact that PSD ratings following hand carriage were some of the highest for the study despite the short hand carriage performance times (2.7 minutes on average). With hand carriage, PSD was reported in the hands, forearms, and upper arms. Pressure exerted on the hands by the load mass, and fatigue generated in the forearms and upper arm muscle masses probably account for this. There was little PSD reported in any other body part for this method of carriage.

Other load carriage methods resulted in much longer performance times than hand carriage, but these methods had similar or lower PSD ratings in other body parts. For shoulder carriage, PSD was elevated in the anterior and posterior neck, posterior shoulders, anterior chest and

upper back. These results are almost identical to those reported by Rice et al. (1996b) except that Rice et al. reported more PSD in the posterior thigh and calves with their two shoulder harness systems. In our study, when subjects carried the load with the shoulder method, the load rested primarily on the shoulders, and the pressure exerted by the load on this body part probably accounts for the higher ratings here. Also, the design of the shoulder system was such that once the mass of the stretcher was on the aluminum hooks, the straps tended to exert a compressive force on the chest and upper back. Many subjects complained of chest pressure while using and after using the cross-shoulder straps, probably accounting for the high ratings in the upper chest and back.

For both the hip-shoulder and LCE methods, subjects reported higher PSD levels in the hips and buttocks, thighs, and anterior lower leg. For the hip-shoulder system, higher PSD was reported in the posterior shoulders, compared to the LCE system; for the LCE system, the hip and abdomen ratings were higher, compared to the hip-shoulder method. Both the hip-shoulder and LCE systems were designed to take the load off the hands and place it on the large muscle groups of the back, shoulders, and legs. The PSD ratings suggest this was successful, although for the LCE system, there was less PSD in the shoulders and back and much more in the anterior hip area. This may have been because we tightened the pistol belt on the LCE to achieve a more effective loading on the hips; this may have reduced the shoulder-back load in the present study but increased the PSD in the hip area. On the other hand, the hip-shoulder method allowed load shifting between the shoulder and hip areas, and some subjects took advantage of this, adjusting the load during the treadmill walk. This distributed the load across different body parts and resulted in the more widely dispersed and lower ratings of PSD.

Of interest was the fact that anterior forearm PSD was somewhat higher for the LCE system than for the hip-shoulder system. There was no opportunity to adjust the load distribution with the LCE system, and subjects may have chosen to relieve hip pressure by grasping and lifting the stretcher handles more often with the LCE system than with the hip-shoulder system. This could tax the finger flexor muscles (located in the forearm), resulting in more subjective discomfort in this area.

Cardiorespiratory Responses During Hand Carriage

Hand carriage resulted in substantially higher minute ventilation, ventilatory equivalent, and heart rate compared to the three alternate forms of stretcher carriage. These greater cardiorespiratory responses can be understood by considering the muscle mass used and the load on these muscles during hand carriage. In order for the hands to grasp the stretcher handles, the

finger flexor muscle group of the forearm was primarily used (although some hand muscles, notably the interossei, adductors, and flexors of the pollicus, and the flexor digiti minimi brevis, were also probably involved) (Hollinshead, 1976). These are the same muscle groups used in the grip strength test (although the hand orientation is different). Correlations between hand grip strength and hand carriage times were 0.63 and 0.73 ($p < 0.05$) for the right and left hand, respectively, and the correlation between estimated forearm cross-sectional bone plus muscle mass and hand carriage time was 0.86. When subjects were carrying the stretcher by hand, the mass held by each hand was about 22.5 kg. Based on hand grip data, estimates of the percent maximum voluntary contraction (MVC) during hand carriage averaged 47% MVC for the right hand and 51% MVC for the left hand; individual values ranged from 33% to 83% MVC.

Previous studies (Gaffney, Sjogaard, & Saltin, 1990; Lind & McNicol, 1967; Shepherd, Blomqvist, Lind, & Mitchell, 1981; Sjogaard, Savard, & Juel, 1988) have shown that contraction at or below 10% to 15% MVC can be sustained for long periods of time; heart rate, blood pressure, and blood flow rise initially, then stabilize. At 20% to 30% MVC, there is a progressive rise in these measures and contractions can be sustained only for limited periods. At 50% MVC, blood pressure and heart rate rise even more rapidly, blood flow is partially occluded, and contraction time is very short. When rhythmic leg contractions at 10% MVC (similar to those probably induced by locomotion in the present study) are superimposed on hand grip exercise at 50% MVC, there are further reductions in forearm blood flow, relative to hand grip contractions alone (Ogita & Kagaya, 1996). The blood flow occlusion is presumably attributable to a number of factors including mechanical compression of the blood vessels caused by tension developed in the active muscles and a centrally mediated sympathetic vasoconstrictor activity that is unable to overcome the local metabolic vasodilator activity (Gaffney, et al., 1990). The metabolic demand for contractile energy in the face of ischemia and the consequential reduced ability of the muscles to remove lactate and other metabolic by-products can be expected to severely challenge the muscles' ability to sustain contractions during hand stretcher carriage.

In our study, hand carriage resulted in a continuous rise in ventilation and consequently, a rise in the ventilatory equivalent since oxygen uptake initially rose and then stabilized. Although there is some controversy (Brooks, 1985), a disproportionate rise in ventilation (relative to VO_2) is usually taken as an indication of whole-body lactate accumulation (Davis, 1985). During static contractions, there is an increase in blood lactate, which eventually increases acidity and interferes with enzymatic processes (Bertocci & Gollnick, 1985; Gaffney, et al., 1990), leading to fatigue. Although the causes of blood lactate accumulation during whole-body exercise are complex (Stainsby & Brooks, 1990), a large portion can be attributed to the anaerobic breakdown of muscle glycogen and blood glucose to supply energy for muscle contraction (Gollnick &

Hermansen, 1973). Sustained static contractions above 20% MVC lead to high venous blood lactate levels (Bystrom & Fransson-Hall, 1994; Gaffney, et al., 1990; Sjogaard, et al., 1988), which is even higher after the contraction (Gaffney, et al., 1990). During contraction, there is probably considerable intramuscular lactate accumulation in the active muscles because of the reduced blood flow; the high post-contraction blood lactate is attributable to release upon return of blood flow (Gaffney, et al., 1990). In the present study, the high ventilation during hand carriage may have been associated with higher lactate levels from the breakdown of muscle glycogen to provide energy for the contraction in the finger flexor muscle groups. Fatigue can have many mechanisms, depending on the nature of the exercise (Enoka & Stuart, 1992), but it seems reasonable to assume that during hand carriage, fatigue may be attributed to lactate accumulation (reflected in the ventilation), increased intramuscular acidity, electrolyte imbalances reducing muscular excitability, and an accumulation of metabolic by-products (compounded by reduced blood flow) that reduced the forearm's muscles ability to sustain the contraction at the level of force necessary to hold the stretcher (Gaffney, et al., 1990; McKenna, 1992; Sahlin, 1992; Sjogaard, et al., 1988).

During hand carriage in our study, heart rates rose almost progressively until subjects were unable to continue. The heart rate rise is in consonance with previous studies examining hand stretcher carriage (Lind & McNicol, 1968; Rice, et al., 1996b). The initial increase in heart rate during isometric contractions appears to be attributable to central withdrawal of vagal inhibition on the heart. The continued rise in heart rate is probably attributable to the action of metabolic receptors or central sympathetic activity resulting from the effort to maintain the contraction (Ramos, et al., 1973; Shepherd, et al., 1981). Interestingly, when Ogita and Kagaya (1996) specifically studied rhythmic lower body exercise at 10% MVC superimposed on hand grip exercise at 50% MVC, they found that the change in heart rate was lower than would be expected from a simple summation of the two types of exercises. They hypothesized that an increase in central venous return (because of the increase in active muscle mass) increased cardiac filling pressure, thus increasing stroke volume; heart rate was lower than expected to maintain the same cardiac output (Ogita & Kagaya, 1996).

Cardiorespiratory Responses With Alternate Stretcher Carriage Methods

General Considerations

In contrast to hand carriage, the other three forms of stretcher carriage resulted in an initial rise in heart rate and ventilation, but these measures achieved a plateau after a few minutes of walking. As mentioned before, when muscle groups are contracting below about 10% to 15% MVC, the exercise can be sustained for long periods of time, and heart rate, blood pressure, and

blood flow stabilize after a few minutes (Gaffney, et al., 1990; Lind & McNicol, 1967; Shepherd, et al., 1981; Sjogaard, et al., 1988). In the present study, the cardiorespiratory responses during the alternate stretcher carriage trials suggest that no single muscle group was taxed more than 15% MVC and that these alternate methods spread the stretcher mass over a larger amount of muscle tissue. The exact musculature involved cannot be accurately described for the alternate methods of carriage, but the broad regions would include the shoulder and abdominal and back musculature necessary to stabilize the trunk. At any rate, the cardiorespiratory data indicate that all the alternate methods were successful in considerably reducing cardiorespiratory strain relative to hand carriage.

Energy Cost

Energy cost is directly proportional to oxygen uptake, with 1 liter of oxygen the approximate energy equivalent of about 5 kcal of energy, assuming the subject is at a steady rate of oxygen consumption (Lusk, 1928). This makes it impossible to consider the aerobic energy cost of hand carriage, based on data collected here. Most subjects did not reach a steady rate of oxygen uptake, and (as discussed before) the fact that ventilation rose continuously suggests that anaerobic metabolism contributed a large portion of the energy production for this form of stretcher carriage. Thus, the discussion of energy cost is limited to the three alternate forms of load carriage.

It was of interest that the cross-shoulder carriage method had somewhat lower energy cost than the LCE and hip-shoulder methods early in the exercise. This was statistically significant only at 5 minutes, but there was a definite trend for the first 3 to 7.5 minutes. This may have been attributable to fewer accessory movements of subjects during the cross-shoulder carriage. Few adjustments could be made with this form of carriage, and subjects tended to maintain a steady, upright posture. With the hip-shoulder and LCE methods, subjects made some posture adjustments in order to better place the load on their bodies with these carriage systems, especially early in the treadmill walks. These accessory movements may have increased the energy cost.

There also appears to have been a slight energy cost advantage for the hip-shoulder method over the LCE method. This was statistically significant only at 20 minutes, but the trend of lower energy cost with the hip-shoulder method is apparent in Figure 4. The reasons for this are not clear, but it is possible that the ability of the hip-shoulder method to allow for load shifting may have reduced recruitment of additional muscle mass as subjects fatigued, thus reducing energy cost.

Although the maximal aerobic capacity of these subjects is not known, estimates can be made from 3.2-km run times (Mello, Murphy, & Vogel, 1984). The estimated VO_2max of the men and women were 52.8 and 38.4 $\text{ml/kg}\cdot\text{min}$, respectively. For the entire group, the estimated VO_2max was 47.5 $\text{ml/kg}\cdot\text{min}$. When energy cost reached a steady rate (after 3 minutes of carriage), VO_2 ranged between about 17 and 21 $\text{ml/kg}\cdot\text{min}$. Thus, the estimated whole-body relative energy expenditure ranged between 36% and 44% VO_2max for the three alternate carriage conditions. It has been demonstrated that self-paced activity can be performed by fit individuals for 1 to 2 hours at a relative energy cost of about 45% VO_2max (Evans, Winsmann, Pandolf, & Goldman, 1980; Levine, Evans, Winsmann, & Pandolf, 1982). However, in the present study, local discomfort because of pressure points caused by the harness systems probably caused many subjects to cease stretcher carriage activity before metabolic limitations were reached.

An interesting question is the additional energy cost that the stretcher carriage imposes over that of walking unloaded. We cannot address this question directly since we did not measure unloaded oxygen uptake, but we can make some estimates. Walking at 3 miles per hour should elicit an oxygen uptake of 11.5 $\text{ml/kg}\cdot\text{min}$, based on the American College of Sports Medicine equation (American College of Sports Medicine, 1990). When the weight of the load carried by the subject is included in the body mass denominator ($\text{ml}\cdot\text{kg}[\text{of body mass} + 45\text{kg}]^{-1}\cdot\text{min}^{-1}$), the resultant oxygen uptakes are very close to this value as shown in Table 15. Averaging oxygen consumption values after steady rate is achieved (Minutes 3 to 30, from Table 15) produces mean values of 11.6, 11.1, and 11.7 $\text{ml}\cdot\text{kg}(\text{of body mass} + 45\text{kg})^{-1}\cdot\text{min}^{-1}$ for the cross-shoulder, hip-shoulder, and LCE systems, respectively. Averaging these same times for the oxygen consumption values in Figure 4 gives average values of 18.7, 18.3, and 19.2 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. These latter values are 61%, 65%, and 64% higher than those correcting for stretcher mass. This is very close to the 62% increase in stretcher mass over average body mass ($45\text{ kg} \div 72.5\text{ kg} \times 100\% = 62\%$). Thus, once subjects reach a steady rate of energy expenditure (after 3 minutes), the alternate stretcher carriage methods apparently imposed an additional energy cost only in proportion to the total mass added to the body. This essentially agrees with previous work of Goldman and colleagues (Goldman & Iampietro, 1962; Soule, Pandolf, & Goldman, 1978).

Table 15

Oxygen Uptake Corrected for Stretcher Mass
(VO₂ in ml*kg [of body mass +45kg]⁻¹*min⁻¹)

Time (min)	Cross-shoulder			Hip-shoulder			LCE		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
1	8.85	1.10	11	8.98	0.97	11	9.10	0.99	11
2	10.98	1.63	11	11.74	1.35	11	11.99	1.51	11
3	11.66	1.12	11	11.88	1.45	11	12.53	0.97	11
4	11.43	1.56	11	12.01	1.55	11	12.33	1.24	11
5	10.98	1.08	11	11.77	1.46	11	12.29	0.97	11
7.5	11.14	1.29	10	11.46	1.48	11	11.74	1.09	11
10	11.05	1.21	7	10.66	1.14	11	11.59	0.82	10
15	10.92	0.85	4	10.60	1.47	9	11.38	0.95	10
20	12.58	1.37	2	10.29	1.10	8	11.26	1.34	6
25	12.36	0.42	2	10.59	1.47	8	11.37	1.64	6
30	12.04	0.18	2	10.40	1.35	8	10.81	1.87	6

Factors Accounting for Hand Carriage Performance

Most of the variance in stretcher hand carriage performance was accounted for by three variables: cross-sectional forearm bone plus muscle mass, cross-sectional thigh muscle mass, and push-up performance. It is well established that muscle cross-sectional area is highly associated with muscle strength (Bruce, Phillips, & Woledge, 1997; Maughan, 1984). Table 16 shows the correlations between the strength measures and total estimated fat-free body mass and cross-sectional muscle areas. It can be seen that forearm bone plus muscle mass was not only highly related to grip strength but also to many of the other strength measures obtained in this study.

Absolute strength is highly related to absolute muscular endurance (Eckert & Day, 1967; Tuttle, Janney, & Salzano, 1955); thus, individuals with greater strength can sustain a muscular contraction for a longer period of time than can those with less strength. In our study, subjects with greater forearm muscle mass presumably had greater absolute muscular endurance and could sustain the 22.5 kg of force necessary to grasp the stretcher for a longer period of time. The forearm muscle mass produced the majority of the force necessary for the hand to grasp the stretcher, thus accounting for the high relationship with hand carriage times.

Table 16
Correlations Between Strength and Various Estimates
of Cross-Sectional Muscle Mass

Strength measure	Fat-free body mass	Cross-sectional muscle or bone plus muscle area		
		Thigh	Upper arm	Forearm
Squat	0.82	0.69	0.77	0.88
Bench press	0.81	0.26	0.88	0.96
Latissimus pulls	0.85	0.41	0.87	0.99
Hand grip (right)	0.85	0.59	0.78	0.93
Hand grip (left)	0.86	0.58	0.71	0.92

The relationship between forearm cross-sectional muscle mass and hand carriage time was independent of gender. Correlations between hand carriage times and forearm cross-sectional bone and muscle area were 0.88 and 0.98 for men and women, respectively, showing a close relationship between these variables, regardless of gender. Gender did not enter into the multivariate analysis, suggesting that it was a less important factor for hand carriage than other variables studied.

More difficult to explain is the variance accounted for by estimated thigh muscle mass and push-ups. Thigh muscle mass is important for locomotion, and the stretcher mass would ultimately be transmitted to the legs. Table 16 shows the correlations between thigh muscle area and the various strength measures. There is a somewhat higher relationship between leg strength (measured with the squat) and thigh muscle area than between thigh muscle area and the other strength measures. Subjects with greater thigh muscle mass may be able to walk with and bear the stretcher load more effectively.

Many studies that use factor analysis have shown that push-ups have high factor loadings on variables reflecting upper body or whole body muscular strength or muscular endurance (Baumgartner & Zuidemia, 1972; Fleishman, 1964; Larson, 1941; McCloy, 1956; Zuidemia & Baumgartner, 1974). In our study, push-ups may have accounted for aspects of upper body or whole body strength or muscular endurance not demarcated by cross-sectional forearm or thigh muscle area alone.

The only other study to examine factors accounting for two-person hand stretcher carriage was that of Rice and Sharp (1994). They used a forward stepwise regression procedure based on data from 12 men and 11 women. Their dependent variable was hand carriage time, and their independent variables included APFT raw scores, stature, body mass, and a number of strength measures. Only grip strength ("grip 3") entered their regression model, accounting for 74% of the variance in hand carriage time. Table 17 shows comparisons of bivariate correlation in the present study with those of Rice and Sharp (1994). Most common measures show similar correlations except for push-ups. Of special note is the similar correlations between hand carriage time and hand grip strength. The methods used in the two studies were similar, although Rice and Sharp examined the dominant hand and we measured the right and left separately. In our multiple regression equation, estimated forearm cross-sectional bone plus muscle mass accounted for more of the hand carriage variance. However, this finding is consistent with those of Rice and Sharp because the hand grip test involves the forearm muscles and cross-sectional area muscle area is highly related to strength (Maughan, 1984). Further, the correlation between hand grip strength and forearm cross-sectional area was high in our study (see Table 16).

Table 17
Correlations Between Hand Carriage Time and Various Strength and Physical
Performance Variables in Two Independent Studies

Variable	Rice and Sharp (1994)	Present study
Upright pull strength	0.51	DNM ^a
Squat strength	DNM ^a	0.50
Dead lift strength	0.75	DNM ^a
Incremental dynamic lift strength	0.78	DNM ^a
Lat pull strength	DNM ^a	0.77
Bench press strength	0.64	0.70
Hand grip strength (right hand)	DNM ^a	0.63
Hand grip strength (left hand)	DNM ^a	0.73
Hand grip strength (dominant hand, "grip 1")	0.76	DNM ^a
Push-ups	0.02	0.28
Sit-ups	-0.28	-0.38
3.2-km run	-0.44	-0.35
Body mass	0.66	0.63
Stature	0.79	0.71

^aDNM = did not measure

Pre- and Post-Exercise Hand Grip

Hand Carriage

Maximum voluntary hand grip strength was severely reduced following hand carriage (21% and 42% on the right and left sides, respectively). We obtained hand grip measures within 1 minute of the time subjects ceased the hand carriage exercise so this strength decline probably represents the residual effects of fatigue in the forearm and hand muscles, attributable to intramuscular lactate accumulation, increased acidity, electrolyte imbalances, and metabolic by-product accumulation (McKenna, 1992; Sahlin, 1992), as discussed before. In addition, we noticed that subjects had difficulty even grasping the hand grip apparatus, suggesting their coordination was impaired. We did not follow the time course of recovery but the reduced strength (and our observation that coordination appeared to be impaired) could be important on a practical level for tasks requiring use of the finger flexor muscles following hand stretcher carriage. In fact, Rice et al. (1996b) demonstrated that stretcher hand carriage resulted in a greater post-carriage performance decrement on a fine motor task when compared to harness carriage.

Cross-Shoulder Carriage

In our study, right hand grip strength was also reduced after carriage with the cross-shoulder method by 11%. This was much less than that observed with hand carriage but is still a significant amount of loss from a practical standpoint. The cross-shoulder harness put the load pressure on the shoulders where the brachial plexus is located. A previous investigation reported a reduction in relative muscular endurance (60% MVC) as a result of carrying rucksacks for long periods, and the greater the rucksack mass, the greater the endurance decrement (Funahashi, 1978). Also, road marches with heavy rucksacks, which put much of the load pressure on the shoulder, result in decrements in upper body power (Harper, Knapik, & de Pontbriand, 1997; Knapik, et al., 1991).

Carrying heavy loads on the shoulders for long periods of time can result in rucksack palsy which is hypothesized to be attributable to a traction injury of the C5 or C6 nerve roots or entrapment of the long thoracic nerve (Bessen, Belcher, & Franklin, 1987; Wilson, 1987). Symptoms of rucksack palsy include numbness, paralysis, and minor pain in the shoulder girdle, elbow flexors, and wrist extensors. Some subjects in our study reported similar sensory motor symptoms after the shoulder carriage. It is possible that the ventral rami of the C5 to T1 spinal nerves may have been compressed by the cross-shoulder straps and this may have resulted in a neurapraxia. This neurapraxia may have resulted in a reduction in central neural output that was manifested as a reduction in hand grip strength.

An alternate explanation may simply be that subjects grasped and held the stretcher with their hands more often during cross-shoulder carriage. Since the cross-shoulder harness tended to be more uncomfortable than the other two harnesses (based on the utility questionnaire) and tended to sit at essentially one location on the shoulder (based on observation), it is possible that subjects grasped the stretcher handles more often, resulting in more fatigue in the hand and forearm muscles.

However, this does not explain why only right-hand grip and not left-hand grip strength was influenced significantly following the cross-shoulder carriage. There was a slight decline of 7% on average on the left side, but this was not statistically significant and not all subjects experienced a post-carry loss of strength. It may be that subjects "favored" their right shoulder and adjusted their body to placing more of the load on the right side. Alternately, they may have tended to lift the stretcher more often with their right hand to relieve shoulder pressure.

Hip-Shoulder and LCE Carriage

The hip-shoulder and LCE methods resulted in no significant reductions in maximal voluntary hand grip strength. It is important to contrast this with strength reductions in the hand carriage and cross-shoulder conditions. It would appear that loads carried primarily on the hips (LCE method) or loads allowed to shift between the hips and shoulders (hip-shoulder method) may be less susceptible to losses in hand grip strength. This has obvious practical importance for post-carry performance of tasks involving the hand grip muscles.

Observation of Fatigue Manifestation in Hand Carriage

Fatigue with hand carriage was consistently manifested by the fingers of the left hand opening and the stretcher slipping from that hand. The right hand was beginning to lose its grip also but was generally still grasping the stretcher. This phenomenon may have been attributable to the greater relative load on the left hand. As noted before, hand grip-derived estimates of the percent MVC during hand carriage averaged 47% for the right hand and 51% for the left hand. Since the relative load on the left hand was greater, it may have fatigued earlier.

RECOMMENDATIONS

- Continue further developmental work on the hip-shoulder and LCE systems. While the LCE system is most practical in field environments, the hip-shoulder system may have uses in

civilian endeavors and in specific military garrison environments where soldiers are not wearing their LCE.

- Improve the hip-shoulder harness by providing lateral stiffeners in the hip belt that may help reduce point pressures on the hips.

- Improve the LCE system by providing a broader plastic clip and minimize mass on the lower portion of the clip. Providing appropriate padding on the lower part of the system may also help.

- Replace the closed fabric loops that hold the stretcher handles on both the hip-shoulder and LCE systems. Open metal loops, possibly similar to the those used on the cross-shoulder system, may be an appropriate alternative. Open metal loops should allow the carrier to more easily place and displace the handles from the systems.

- Test the hip-shoulder and LCE systems (after these changes are made and pilot tested) in a realistic environment. This would involve examining the full range of stretcher carriage activities including placing the manikin on the stretcher, lifting the stretcher, walking with it and placing it into an air or ground ambulance.

REFERENCES

- Ahlborg, G., & Felig, P. (1982). Lactate and glucose exchange across the forearm, legs, and splanchnic bed during and after prolonged exercise. Journal of Clinical Investigation, 69, 45-54.
- American College of Sports Medicine (1990). Guidelines for exercise testing and prescription. Philadelphia: Lea and Febiger.
- Army Development and Employment Agency (1987). Report on the ADEA soldier's load initiative No. Ft Lewis, WA: Army Development and Employment Agency.
- Baumgartner, T.A., & Zuidema, M.A. (1972). Factor analysis of physical fitness tests. Research Quarterly, 43, 443-450.
- Bertocci, L.A., & Gollnick, P.D. (1985). Ph effect on mitochondria and individual enzyme function. Medicine and Science in Sports and Exercise, 17, 244.
- Bessen, R.J., Belcher, V.W., & Franklin, R.J. (1987). Rucksack paralysis with and without rucksack frames. Military Medicine, 152, 372-375.
- Borg, G. (1970). Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitation Medicine, 2-3, 92-98.
- Brooks, G.A. (1985). Anaerobic threshold: Review of the concept and directions for further research. Medicine and Science in Sports and Exercise, 17, 22-31.
- Bruce, S.A., Phillips, S.K., & Woledge, R.C. (1997). Interpreting the relationship between force and cross-sectional area in human muscle. Medicine and Science in Sports and Exercise, 29, 677-683.
- Bystrom, S., & Fransson-Hall, C. (1994). Acceptability of intermittent handgrip contractions based on physiological responses. Human Factors, 36, 158-171.
- Chatterjee, S., & Price, B. (1991). Regression analysis by example. New York: John Wiley & Sons, Inc.
- Davis, J.A. (1985). Anaerobic threshold: review of the concept and directions for future research. Medicine and Science in Sports and Exercise, 17, 6-18.
- Department of Labor (1991). The revised handbook for analyzing jobs. Washington DC: U.S. Government Printing Office.
- Eckert, H., & Day, J.O. (1967). Relationship between strength and workload in pushups. Research Quarterly for Exercise and Sport, 38, 380-383.

- Enoka, R.M., & Stuart, D.G. (1992). Neurobiology of muscle fatigue. Journal of Applied Physiology, 72, 1631-1648.
- Evans, W.J., Winsmann, F.R., Pandolf, K.B., & Goldman, R. (1980). Self-paced hard work comparing men and women. Ergonomics, 23, 613-621.
- Fleck, S.J., & Kraemer, W.J. (1987). Designing resistance training programs. Champaign IL: Human Kinetic Publishers.
- Fleishman, E.A. (1964). The structure and measurement of physical fitness. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Funahashi, A. (1978). Depressant effect of rucksack-induced branchial plexus cord squeeze on endurance of isometric strength and simple reaction time. Journal of Science and Labor (Japan), 54, 373-378.
- Gaffney, F.A., Sjogaard, G., & Saltin, B. (1990). Cardiovascular and metabolic responses to static contractions in man. Acta Physiologica Scandinavica, 138, 249-258.
- Goldman, R.F., & Iampietro, P.F. (1962). Energy cost of load carriage. Journal of Applied Physiology, 17, 675-676.
- Gollnick, P.D., & Hermansen, L. (1973). Biochemical adaptations to exercise: Anaerobic metabolism. In J.H. Wilmore (Eds.), Exercise and Sports Science Reviews (pp. 1-43). New York: Academic Press.
- Gordon, C.C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T., Tebbetts, I., & Walker, R.A. (1989). 1988 anthropometric survey of U.S. Army personnel: methods and summary statistics (Technical Report No. No. TR-89/044). Natick MA: U.S. Army Natick Research Development and Engineering Center.
- Harper, W.H., Knapik, J.J., & de Pontbriand, R.J. (1997). An investigation of female load carriage capability (Technical Report No. ARL-TR-1176). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.
- Headquarters, Department of the Army (1989). Use of volunteers as subjects of research (Army Regulation [AR] 70-25). Washington DC: Author.
- Headquarters, Department of the Army (1994). Military Occupational Classification and Structure (AR 611-201). Washington DC: Author.
- Heymsfield, S.B., McManus, C., Smith, J., Stevens, V., & Nixon, D.W. (1982). Anthropometric measurement of muscle mass: Revised equations for calculating bone-free arm muscle area. American Journal of Clinical Nutrition, 36, 680-690.

- Holewijn, M., & Lotens, W.A. (1992). The influence of backpack design on physical performance. Ergonomics, 35, 149-157.
- Hollinshead, W.H. (1976). Functional anatomy of the limbs and back. Philadelphia: W.B. Saunders.
- Knapik, J.J., Bahrke, M., Staab, J.S., Reynolds, K., Vogel, J., & O'Connor, J. (1990). Frequency of loaded road march training and performance on a loaded road march (Technical Report No. T13-90). Natick MA: U.S. Army Research Institute of Environmental Medicine.
- Knapik, J.J., Harman, E.A., & Reynolds, K. (1996). Load carriage using packs: a review of physiological, biomechanical and medical aspects. Applied Ergonomics, 27, 207-216.
- Knapik, J.J., de Pontbriand, R.J., Harper, W.H, Tauson, R.A., Swoboda, J.C., & Doss, N.W. (1997). Feasibility of MOS task analysis and redesign to reduce physical demands in the U.S. Army (technical report in press). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.
- Knapik, J.J., & Reynolds, K. (in press). Load carriage in military operations: A review of historical, physiological, biomechanical and medical aspects. In R. Burr & P. Amoroso (Eds.), Textbook of Military Medicine.
- Knapik, J.J., Staab, J.S., Bahrke, M., Reynolds, K., Vogel, J., & O'Conner, J. (1991). Soldier performance and mood states following strenuous road marching. Military Medicine, 156, 197- 200.
- Knapik, J.J., Staab, J.S., & Harman, E.A. (1996). Validity of an anthropometric estimate of thigh muscle cross-sectional area. Medicine and Science in Sports and Exercise, 28, 1523-1530.
- Larson, L.A. (1941). A factor and validity analysis of strength variables and tests with a test combination of chinning, dipping and vertical jump. Research Quarterly, 12, 82-96.
- Levine, L., Evans, W.J., Winsmann, F.R., & Pandolf, K.B. (1982). Prolonged self-paced hard physical exercise comparing trained men and untrained men. Ergonomics, 25, 393-400.
- Lind, A.R., & McNicol, G.W. (1967). Muscular factors which determine the cardiovascular responses to sustained and rhythmic exercise. Canadian Medical Association Journal, 96, 706-713.
- Lind, A.R., & McNicol, G.W. (1968). Cardiovascular responses to holding and carrying weights by hands and by shoulder harness. Journal of Applied Physiology, 25, 261-267.
- Lusk, G. (1928). The elements of the science of nutrition. New York: Academic Press.
- Maughan, R.J. (1984). Relationship between muscle strength and cross-sectional area. Sports Medicine, 1, 263-269.

- Maxwell, A.E. (1974). The logistic transformation in the analysis of paired comparison data. British Journal of Mathematical and Statistical Psychology, 27, 62-71.
- McCloy, C.H. (1956). A factor analysis of tests of endurance. Research Quarterly, 27, 213-216.
- McKenna, M.J. (1992). The role of ionic processes in muscular fatigue during intense exercise. Sports Medicine, 13, 134-145.
- Mello, R.P., Murphy, M.M., & Vogel, J.A. (1984). Relationship between the Army two mile run test and maximal oxygen uptake. (Technical Report No. T3/85). Natick, MA: U.S. Army Research Institute of Environmental Medicine.
- Mundale, M.O. (1970). Study of the relationship of endurance during isometric exercise to strength of isometric contraction of muscles of the hand grip. Master's Thesis, University of Minnesota.
- Ogita, F., & Kagaya, A. (1996). Differential cardiorespiratory responses to combined exercise with different combinations of forearm and calf exercise. European Journal of Applied Physiology, 73, 511-515.
- Ramos, M.U., & Knapik, J.J. (1979). Instrumentation and techniques for the measurement of muscular strength and endurance in the human body (Technical Report No. T2-80). Natick, MA: United States Army Research Institute of Environmental Medicine.
- Ramos, M.U., Mundale, M.O., Awad, E.A., Witsoe, D.A., Cole, T.M., Olson, M., & Kottke, F.J. (1973). Cardiovascular effects of spreading excitation during prolonged isometric exercise. Archives of Physical Medicine and Rehabilitation, 54, 496-505.
- Rice, V.J.B. (1992). A usability assessment of two harnesses for stretcher carriage. In S. Kumar (Eds.), Advances in Industrial Ergonomics and Safety IV (pp. 1269-1274). New York: Francis and Taylor.
- Rice, V.J.B., & Sharp, M.A. (1994). Prediction of performance on two stretcher-carry tasks. Work, 4, 201-210.
- Rice, V.J.B., Sharp, M.A., Tharion, W.J., & Williamson, T.L. (1996a). The effect of gender, team size, and a shoulder harness on a stretcher carry task and post task performance: Part II. A mass-casualty situation. International Journal of Industrial Ergonomics, 18, 41-49.
- Rice, V.J.B., Sharp, M.A., Tharion, W.J., & Williamson, T.L. (1996b). The effects of gender, team size, and a shoulder harness on the stretcher-carry task and post task performance. Part I. A simulated carry from a remote site. International Journal of Industrial Ergonomics, 18, 27-40.
- Sahlin, K. (1992). Metabolic factors in fatigue. Sports Medicine, 13, 99-107.

- Sharp, M.A., Wright, J.E., & Vogel, J.A. (1985). Performance on selected candidate screening test procedures before and after Army Basic and Advanced Individual Training (Technical Report No. T13/85). Natick, MA: U.S. Army Research Institute of Environmental Medicine.
- Shepherd, J.T., Blomqvist, C.G., Lind, A.R., & Mitchell, J.H. (1981). Static (isometric) exercise. Circulation Research, 48, (Suppl 1), I-179 - I-188.
- Sjogaard, G., Savard, G., & Juel, C. (1988). Muscle blood flow during isometric activity and its relation to fatigue. European Journal of Applied Physiology, 57, 327-335.
- Soule, R.G., Pandolf, K.B., & Goldman, R.F. (1978). Energy expenditure of heavy load carriage. Ergonomics, 21, 373-381.
- Stainsby, W.N., & Brooks, G.A. (1990). Control of lactic acid metabolism in contracting muscles and during exercise. Exercise and Sports Science Reviews, 18, 29-63.
- Tharion, W.J., Rice, V., Sharp, M.A., & Marlow, B.E. (1993). The effects of litter carrying on rifle shooting. Military Medicine, 158, 566-570.
- Tuttle, W., Janney, C., & Salzano, J. (1955). Relation of maximal back and leg strength to back and leg endurance. Research Quarterly for Exercise and Sport, 26, 96-106.
- Vogel, J.A., Kirkpatrick, J.W., Fitzgerald, P.I., Hodgdon, J.A., & Harman, E.A. (1984). Derivation of anthropometry based body fat equations for the Army's weight control program (Technical Report No. 17-88). Natick, MA: U.S. Army Research Institute of Environmental Medicine.
- Wilson, W.J. (1987). Brachial plexus palsy in basic trainees. Military Medicine, 152, 519-522.
- Zuidema, M.A., & Baumgartner, T.A. (1974). Second factor analysis study of physical fitness tests. Research Quarterly, 42, 247-256.

APPENDIX A
RATING OF PERCEIVED EXERTION

RATING OF PERCEIVED EXERTION

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

APPENDIX B

SORENESS, PAIN, AND DISCOMFORT QUESTIONNAIRE

SORENESS, PAIN AND DISCOMFORT QUESTIONNAIRE

INSTRUCTIONS: RATE THE DEGREE OF SORENESS, PAIN OR DISCOMFORT THAT YOU ARE CURRENTLY FEELING FOR BODY PARTS 1-11. DO SO FOR THE FRONT AND THE BACK OF THE BODY.

NAME: _____

SOLDIER NUMBER: _____

SSN: _____

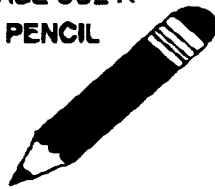
FILL IN YOUR
NUMBER

0
1
2
3
4
5
6
7
8
9

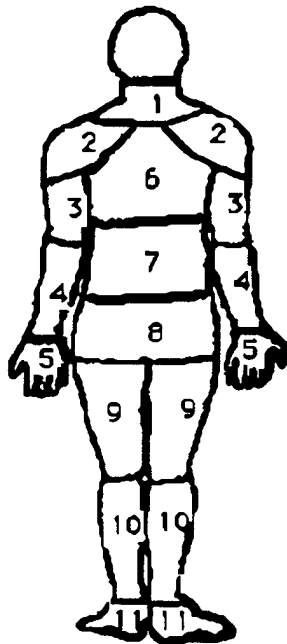
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

PLEASE USE A
#2 PENCIL

Proper
Mark



FRONT OF BODY



NONE
VERY SLIGHT
MILD
MODERATE
SEVERE
EXTREME

1	2	3	4	5	6	7	8	9	10	11

BACK OF BODY

NONE
VERY SLIGHT
MILD
MODERATE
SEVERE
EXTREME

1	2	3	4	5	6	7	8	9	10	11

APPENDIX C
UTILITY QUESTIONNAIRE

APPENDIX D
PAIRED COMPARISON QUESTIONNAIRE

PAIRED COMPARISON QUESTIONNAIRE

Circle your choice if you had to select only between the two choices presented. After completing a page do not go back to a previous page.

(Page 1)

Hands or LCE-integrated

(Page 2)

Hands or hip-shoulder harness

(Page 3)

Hands or shoulder harness

(Page 4)

LCE-integrated or hip-shoulder harness

(Page 5)

LCE-integrated or shoulder harness

(Page 6)

Hip-shoulder harness or shoulder harness

APPENDIX E

DESCRIPTIVE STATISTICS FOR THE PRE-TEST MEASURES

DESCRIPTIVE STATISTICS FOR THE PRE-TEST MEASURES

Table E-1

Anthropometric and Body Composition Characteristics of the Subjects

Measure	Men (n=7)		Women (n=4)		Group (n=11)	
	M	SD	M	SD	M	SD
Age (years)	23.6	3.7	23.3	1.7	23.5	3.4
Stature (cm)	172.0	3.0	163.3	6.0	168.8	8.2
Body mass (kg)	72.5	11.1	65.7	4.5	70.1	9.6
Body fat (percent)	19.4	3.8	29.4	5.5	23.0	6.3
Fat-free body mass (kg)	57.8	7.3	46.3	2.1	53.9	8.0
Acromial height (cm)	140.3	7.8	133.8	5.7	137.9	7.6
Axilla height (cm)	128.7	7.2	123.3	6.0	126.7	7.0
Chest height (cm)	125.1	6.9	118.7	6.5	122.8	7.2
Waist height (cm)	110.5	6.1	106.2	4.5	108.9	5.8
Iliocristale height (cm)	104.7	7.2	97.8	5.3	102.1	7.2
Biacromial breadth (cm)	40.5	1.8	36.2	1.0	39.0	2.6
Interscye I (cm)	39.0	1.7	36.3	1.5	38.0	2.1
Chest breadth (cm)	31.7	2.3	28.1	1.9	30.4	2.8
Chest depth (cm)	23.4	2.0	23.1	2.2	23.3	2.0
Strap length (cm)	70.2	3.9	65.9	4.8	68.6	4.5
Chest circumference (cm)	96.2	5.8	90.2	7.7	94.0	6.9
Sitting height (cm)	90.1	3.8	85.8	2.9	88.5	4.0
Acromial height (cm)	58.0	4.0	57.1	2.5	58.7	3.4

Table E-2

Strength and APFT Measures

Measure	Men		Women		Group	
	M	SD	M	SD	M	SD
Squat (kg)	93.5	6.5	48.9	12.5	77.3	27.0
Latissimus pulls (kg)	64.0	3.4	34.7	5.0	53.3	16.6
Bench press (kg)	82.8	5.0	37.5	8.6	66.3	25.5
Right-hand grip (kg)	64.0	13.2	36.0	7.8	53.9	18.0
Left-hand grip (kg)	54.9	8.7	34.5	5.8	47.5	12.7
Push-ups (reps)	66.7	11.6	33.3	10.4	54.5	19.9
Sit-ups (reps)	62.0	9.1	60.3	11.1	61.4	9.3
3.2-km run (min)	14.0	0.4	19.5	2.0	16.0	3.0
Total APFT score (points)	245.6	12.3	206.0	29.6	231.2	27.4

Table E-3

Muscle and Bone and Muscle Cross-Sectional Area Estimates

Measure	Men		Women		Group	
	M	SD	M	SD	M	SD
Upper arm muscle and bone area (cm ²)	48.7	7.0	34.0	5.5	43.4	9.7
Forearm bone and muscle area (cm ²)	53.0	6.0	36.6	3.2	45.7	9.8
Thigh muscle area (cm ²)	133.9	31.3	110.2	4.6	125.3	27.2

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
2	ADMINISTRATOR DEFENSE TECHNICAL INFO CENTER ATTN DTIC DDA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218	1	DPTY ASST SCY FOR RSRCH & TECH SARD-TT F MILTON RM 3EA79 THE PENTAGON WASHINGTON DC 20310-0103
1	DIRECTOR US ARMY RESEARCH LABORATORY ATTN AMSRL CS AL TA RECORDS MANAGEMENT 2800 POWDER MILL RD ADELPHI MD 20783-1197	1	ODCSOPS D SCHMIDT WASHINGTON DC 20310-1001
1	DIRECTOR US ARMY RESEARCH LABORATORY ATTN AMSRL CI LL TECHNICAL LIBRARY 2800 POWDER MILL RD ADELPHI MD 207830-1197	1	OSD OUSD(A&T)/ODDDR&E(R) J LUPO THE PENTAGON WASHINGTON DC 20301-7100
1	DIRECTOR US ARMY RESEARCH LABORATORY ATTN AMSRL CS AL TP TECH PUBLISHING BRANCH 2800 POWDER MILL RD ADELPHI MD 20783-1197	1	USAASA MOAS-AI W PARRON 9325 GUNSTON RD STE N319 FT BELVOIR VA 22060-5582
1	CECOM SP & TERRESTRIAL COM DIV ATTN AMSEL RD ST MC M H SOICHER FT MONMOUTH NJ 07703-5203	1	CECOM PM GPS COL S YOUNG FT MONMOUTH NJ 07703
1	PRIN DPTY FOR TECH GY HDQ US ARMY MATL CMND ATTN AMCDCG T M FISETTE 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001	1	GPS JOINT PROG OFC DIR COL J CLAY 2435 VELA WAY STE 1613 LOS ANGELES AFB CA 90245-5500
1	PRIN DPTY FOR ACQTN HDQ US ARMY MATL CMND ATTN AMCDCG A D ADAMS 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001	3	DARPA L STOTTS J PENNELLA B KASPAR 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	DPTY CG FOR RDE HDQ US ARMY MATL CMND ATTN AMCRD BG BEAUCHAMP 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001	1	DIRECTORATE FOR MANPRINT ATTN DAPE MR DEPUTY CHIEF OF STAFF PERSONNEL 300 ARMY PENTAGON WASHINGTON DC 20310-0300
		1	OUSD(A)/DDDR&E(R&A)/E&LS PENTAGON ROOM 3D129 WASHINGTON DC 20301-3080
		1	CODE 1142PS OFFICE OF NAVAL RESEARCH 800 N QUINCY STREET ARLINGTON VA 22217-5000
		1	WALTER REED ARMY INST OF RSCH ATTN SGRD UWI C (COL REDMOND) WASHINGTON DC 20307-5100

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	COMMANDER US ARMY RESEARCH INSTITUTE ATTN PERI ZT (DR E M JOHNSON) 5001 EISENHOWER AVENUE ALEXANDRIA VA 22333-5600	1	COMMANDER USA AEROMEDICAL RESEARCH LAB ATTN LIBRARY FORT RUCKER AL 36362-5292
1	DEFENSE LOGISTICS STUDIES INFORMATION EXCHANGE ATTN DIRECTOR DLSIE ATSZ DL BLDG 12500 2401 QUARTERS ROAD FORT LEE VA 23801-1705	1	US ARMY SAFETY CENTER ATTN CSSC SE FORT RUCKER AL 36362
1	DEPUTY COMMANDING GENERAL ATTN EXS (Q) MARINE CORPS RD&A COMMAND QUANTICO VA 22134	1	CHIEF ARMY RESEARCH INSTITUTE AVIATION R&D ACTIVITY ATTN PERI IR FORT RUCKER AL 36362-5354
1	HEADQUARTERS USATRADO ATTN ATCD SP FORT MONROE VA 23651	1	US ARMY NATICK RD&E CENTER ATTN STRNC YBA NATICK MA 01760-5020
1	COMMANDER USATRADO COMMAND SAFETY OFFICE ATTN ATOS (MR PESSAGNO/MR LYNE) FORT MONROE VA 23651-5000	1	US ARMY TROOP SUPPORT CMD NATICK RD&E CENTER ATTN BEHAVIORAL SCI DIV SSD NATICK MA 01760-5020
1	COMMANDER US ARMY MATERIEL COMMAND ATTN AMCAM 5001 EISENHOWER AVENUE ALEXANDRIA VA 22333-0001	1	US ARMY TROOP SUPPORT CMD NATICK RD&E CENTER ATTN TECH LIBRARY (STRNC MIL) NATICK MA 01760-5040
1	DIRECTOR TDAD DCST ATTN ATTG C BLDG 161 FORT MONROE VA 23651-5000	1	DR RICHARD JOHNSON HEALTH & PERFORMANCE DIVISION US ARIEM NATICK MA 01760-5007
1	COMMANDER USA OPERATIONAL TEST & EVAL AGENCY ATTN CSTE TSM 4501 FORD AVE ALEXANDRIA VA 22302-1458	1	MEDICAL LIBRARY BLDG 148 NAVAL SUBMARINE MEDICAL RSCH LAB BOX 900 SUBMARINE BASE NEW LONDON GROTON CT 06340
1	USA BIOMEDICAL R&D LABORATORY ATTN LIBRARY FORT DETRICK BUILDING 568 FREDERICK MD 21702-5010	1	USAF ARMSTRONG LAB/CFTO ATTN DR F WESLEY BAUMGARDNER SUSTAINED OPERATIONS BRANCH BROOKS AFB TX 78235-5000
1	HQ USAMRDC ATTN SGRD PLC FORT DETRICK MD 21701	1	COMMANDER USAMC LOGISTICS SUPPORT ACTIVITY ATTN AMXLS AE REDSTONE ARSENAL AL 35898-7466
		1	ARI FIELD UNIT FORT KNOX BUILDING 2423 PERI IK FORT KNOX KY 40121-5620

NO. OF
COPIES ORGANIZATION

1 COMMANDANT
USA ARTILLERY & MISSILE SCHOOL
ATTN USAAMS TECH LIBRARY
FORT SILL OK 73503

1 COMMANDER
WHITE SANDS MISSILE RANGE
ATTN STEWS TE RE
WHITE SANDS MISSILE RANGE NM
88002

1 USA TRADOC ANALYSIS COMMAND
ATTN ATRC WSR (D ANGUIANO)
WHITE SANDS MISSILE RANGE NM
88002-5502

1 STRICOM
12350 RESEARCH PARKWAY
ORLANDO FL 32826-3276

1 COMMANDER
USA TANK-AUTOMOTIVE R&D CENTER
ATTN AMSTA RS/D REES
WARREN MI 48090

1 COMMANDER
USA TANK-AUTOMOTIVE R&D CENTER
ATTN AMSTA TSL (TECH LIBRARY)
WARREN MI 48397-5000

1 INSTITUTE FOR DEFENSE ANALYSES
ATTN DR JESSE ORLANSKY
1801 N BEAUREGARD STREET
ALEXANDRIA VA 22311

1 PURDUE UNIVERSITY
SERIALS UNIT
CDM KARDEX
1535 STEWART CENTER
WEST LAFAYETTE IN 47907-1535

1 GOVT PUBLICATIONS LIBRARY
409 WILSON M
UNIVERSITY OF MINNESOTA
MINNEAPOLIS MN 55455

1 DR RICHARD PEW
BBN SYSTEMS AND TECH CORP
10 MOULTON STREET
CAMBRIDGE MA 02138

1 MR R BEGGS
BOEING-HELICOPTER CO P30-18
PO BOX 16858
PHILADELPHIA PA 19142

NO. OF
COPIES ORGANIZATION

1 DR ROBERT KENNEDY
ESSEX CORPORATION SUITE 227
1040 WOODCOCK ROAD
ORLANDO FL 32803

1 MR LARRY W AVERY
BATTELLE PACIFIC NW LABS
PO BOX 999 MAIL STOP K6-66
RICHLAND WA 99352

1 DR BEN B MORGAN
DEPARTMENT OF PSYCHOLOGY
UNIVERSITY OF CENTRAL FLORIDA
PO BOX 25000
ORLANDO FL 32816

1 AFHRL/CA
BROOKS AFB TX 78235

1 DR ARTHUR S KAMLET
BELL LABORATORIES
6200 EAST BROAD STREET
COLUMBUS OH 43213

1 GENERAL MOTORS CORPORATION
NORTH AMERICAN OPERATIONS
PORTFOLIO ENGINEERING CENTER
HUMAN FACTORS ENGINEERING
ATTN MR A J ARNOLD STAFF PROJ ENG
ENGINEERING BLDG
30200 MOUND RD BOX 9010
WARREN MI 48090-9010

1 GENERAL DYNAMICS
LAND SYSTEMS DIV LIBRARY
PO BOX 1901
WARREN MI 48090

1 DR LLOYD A AVANT
DEPARTMENT OF PSYCHOLOGY
IOWA STATE UNIVERSITY
AMES IA 50010

1 DR PAUL R MCCRIGHT
INDUSTRIAL ENGINEERING DEPT
KANSAS STATE UNIVERSITY
MANHATTA KS 66502

1 DR MM AYOUB DIRECTOR
INST FOR ERGONOMICS RESEARCH
TEXAS TECH UNIVERSITY
LUBBOCK TX 79409

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	MR KENNETH C CROMBIE TECHNICAL LIBRARIAN E104 DELCO SYSTEMS OPERATIONS 6767 HOLLISTER AVENUE GOLETA CA 93117	1	PEO COMBAT SUPPORT ATTN AMCPEO CS US ARMY TANK AUTOMOTIVE CMD WARREN MI 48397-5000
1	MR WALT TRUSZKOWSKI CODE 522.3 NASA/GODDARD SPACE FLIGHT CENTER GREENBELT MD 20771	1	PEO MGMT INFORMATION SYSTEMS ATTN AS PEM STOP C-2 BLDG 1465 FT BELVOIR VA 22060-5456
1	DIRECTOR US ARMY AEROFIGHT DYNAMICS DIR ATTN SAVRT AF D (A W KERR) AMES RESEARCH CENTER (MS 215-1) MOFFETT FIELD CA 94035-1099	1	PEO ARMAMENTS ATTN AMCPEO AR BLDG 171 PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE NATICK MA 01760-5007	1	PEO AIR DEFENSE ATTN SFAE AD S US ARMY MISSILE COMMAND REDSTONE ARSENAL AL 35898-5750
1	DR DANIEL J POND BATTELLE PNL/K6-66 PO BOX 999 RICHLAND WA 99350	1	PEO STRATEGIC DEFENSE PO BOX 15280 ATTN DASD ZA US ARMY STRATEGIC DEFENSE CMD ARLINGTON VA 22215-0280
1	HQDA (DAPE ZXO) ATTN DR FISCHL WASHINGTON DC 20310-0300	1	PROGRAM MANAGER RAH-66 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798
1	HUMAN FACTORS ENG PROGRAM DEPT OF BIOMEDICAL ENGINEERING COLLEGE OF ENGINEERING & COMPUTER SCIENCE WRIGHT STATE UNIVERSITY DAYTON OH 45435	1	DENNIS L SCHMICKLY CREW SYSTEMS ENGINEERING MCDONNELL DOUGLAS HELICOPTER 5000 EAST MCDOWELL ROAD MESA AZ 85205-9797
1	COMMANDER USA MEDICAL R&D COMMAND ATTN SGRD PLC (LTC K FRIEDL) FORT DETRICK MD 21701-5012	1	JON TATRO HUMAN FACTORS SYSTEM DESIGN BELL HELICOPTER TEXTRON INC PO BOX 482 MAIL STOP 6 FT WORTH TX 76101
1	PEO STANDARD ARMY MGMT INFORMATION SYSTEM ATTN AS PES STOP C-3 FT BELVOIR VA 22060-5456	1	CHIEF CREW SYSTEMS INTEGRATION SIKORSKY AIRCRAFT M/S S3258 NORTH MAIN STREET STRATFORD CT 06602
1	PEO ARMORED SYS MODERNIZATION US ARMY TANK-AUTOMOTIVE CMD ATTN SFAE ASM S WARREN MI 48397-5000	1	GENERAL ELECTRIC COMPANY ARMAMENT SYSTEMS DEPT RM 1309 ATTN HF/MANPRINT R C MCLANE LAKESIDE AVENUE BURLINGTON VT 05401-4985
		1	JOHN B SHAFER 250 MAIN STREET OWEGO NY 13827

NO. OF COPIES	ORGANIZATION
1	OASD (FM&P) WASHINGTON DC 20301-4000
1	COMMANDER US ARMY MATERIEL COMMAND ATTN AMCDE AQ 5001 EISENHOWER AVENUE ALEXANDRIA VA 22333
1	COMMANDANT US ARMY ARMOR SCHOOL ATTN ATSB CDS (MR LIPSCOMB) FT KNOX KY 40121-5215
1	COMMANDER US ARMY AVIATION CENTER ATTN ATZQ CDM S (MR MCCracken) FT RUCKER AL 36362-5163
1	COMMANDER US ARMY SIGNAL CTR & FT GORDON ATTN ATZH CDM FT GORDON GA 30905-5090
1	DIRECTOR US ARMY AEROFLIGHT DYNAMICS DIR MAIL STOP 239-9 NASA AMES RESEARCH CENTER MOFFETT FIELD CA 94035-1000
1	PROJECT MANAGER SIGNALS WARFARE ATTN SFAE IEW SG (ALAN LINDLEY) BLDG P-181 VINT HILL FARMS STATION WARRENTON VA 22186-5116
1	COMMANDER MARINE CORPS SYSTEMS COMMAND ATTN CBGT QUANTICO VA 22134-5080
1	DIRECTOR AMC-FIELD ASSIST IN SCIENCE & TECHNOLOGY ATTN AMC-FAST (RICHARD FRANSEEN) FT BELVOIR VA 22060-5606
1	COMMANDER US ARMY FORCES COMMAND ATTN FCDJ SA BLDG 600 AMC FAST SCIENCE ADVISER FT MCPHERSON GA 30330-6000

NO. OF COPIES	ORGANIZATION
1	COMMANDER I CORPS AND FORT LEWIS AMC FAST SCIENCE ADVISER ATTN AFZH CSS FORT LEWIS WA 98433-5000
1	HQ III CORPS & FORT HOOD OFFICE OF THE SCIENCE ADVISER ATTN AFZF CS SA FORT HOOD TX 76544-5056
1	COMMANDER U.S. ARMY NATL TRAINING CENTER AMC FAST SCIENCE ADVISER ATTN AMXLA SA FORT IRWIN CA 92310
1	COMMANDER HQ XVIII ABN CORPS & FORT BRAGG OFFICE OF THE SCI ADV BLDG 1-1621 ATTN AFZA GD FAST FORT BRAGG NC 28307-5000
1	SOUTHCOM WASHINGTON FIELD OFC 1919 SOUTH EADS ST SUITE L09 AMC FAST SCIENCE ADVISER ARLINGTON VA 22202
1	HQ US SPECIAL OPERATIONS CMD AMC FAST SCIENCE ADVISER ATTN SOSD MACDILL AIR FORCE BASE TAMPA FL 33608-0442
1	HQ US ARMY EUROPE AND 7TH ARMY ATTN AEAGX SA OFFICE OF THE SCIENCE ADVISER APO AE 09014
1	COMMANDER HQ 21ST THEATER ARMY AREA CMD AMC FAST SCIENCE ADVISER ATTN AERSA APO AE 09263
1	COMMANDER HEADQUARTERS USEUCOM AMC FAST SCIENCE ADVISER UNIT 30400 BOX 138 APO AE 09128

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	HQ 7TH ARMY TRAINING COMMAND UNIT #28130 AMC FAST SCIENCE ADVISER ATTN AETT SA APO AE 09114	1	US ARMY RESEARCH INSTITUTE ATTN PERI IK (DOROTHY L FINLEY) 2423 MORANDE STREET FORT KNOX KY 40121-5620
1	COMMANDER HHC SOUTHERN EUROPEAN TASK FORCE ATTN AESE SA BUILDING 98 AMC FAST SCIENCE ADVISER APO AE 09630	1	DENNIS SCHMIDT HQDA DAMO FDQ 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	COMMANDER US ARMY PACIFIC AMC FAST SCIENCE ADVISER ATTN APSA FT SHAFTER HI 96858-5L00	1	US MILITARY ACADEMY MATHEMATICAL SCIENCES CENTER OF EXCELLENCE DEPT OF MATHEMATICAL SCIENCES ATTN MDN A MAJ DON ENGEN THAYER HALL WEST POINT NY 10996-1786
1	COMMANDER US ARMY JAPAN/IX CORPS UNIT 45005 ATTN APAJ SA AMC FAST SCIENCE ADVISERS APO AP 96343-0054	1	NAIC/DXLA 4180 WATSON WAY WRIGHT PATTERSON AFB OH 45433-5648
1	AMC FAST SCIENCE ADVISERS PCS #303 BOX 45 CS-SO APO AP 96204-0045	1	USARIEM MARILYN SHARP NATICK LABS NATICK MA 01760
1	COMMANDER ALASKAN COMMAND ATTN SCIENCE ADVISOR (MR GRILLS) 6-900 9TH ST STE 110 ELMENDORF AFB ALASKA 99506	1	HEAD OCC HEALTH SECTION ATTN JOY ERDMAN CHIEF OF NAVAL OPERATIONS (N45) 2000 PENTAGON WASHINGTON DC 20350
1	CDR & DIR USAE WATERWAYS EXPERIMENTAL STATION ATTN CEWES IM MI R (A S CLARK) CD DEPT #1153 3909 HALLS FERRY ROAD VICKSBURG MS 39180-6199	1	SNR OCC HEALTH NURSE ATTN NANCY CRAFT NAVY ENVIRONMENTAL HEALTH CTR 2510 WALMER AVE NORFOLK VA 23513-2617
1	MR GARY PERLMAN COMPUTER & INFORMATION SCIENCE OHIO STATE UNIV RM 228 BOLZ HALL 2036 NEIL AVENUE COLUMBUS OH 43210-1277	1	HQ USACE ATTN CESO I ROBERT STOUT ROOM 4122 C 20 MASSACHUSETTS AVE NW WASHINGTON DC 20314-1000
1	DR SEHCHANG HAH DEPT OF BEHAVIORAL SCIENCES & LEADERSHIP BUILDING 601 ROOM 281 US MILITARY ACADEMY WEST POINT NEW YORK 10996-1784	1	AMEDD CENTER & SCHOOL C OT BRANCH LTC V J B RICE 3141 BING-ENGLEMAN ROAD FORT SAM HOUSTON TX 78234
		1	WRAMC PREVENTIVE MED SVC ATTN MCHL HO MAJ R PIPKIN WASHINGTON DC 20307-5001

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	US ARMY SAFETY CENTER ATTN CSSC RT M L BOND BLDG 4905 5TH AVE 1209 FT RUCKER AL 36362-5363	1	OSD/WHS/RE&F ATTN SEMD SAFETY & OCC HEALTH BR M LANGONE 1155 PENTAGON 2D533 WASHINGTON DC 20301-1155
4	AL/OEMO ATTN MAJ E KLINENBERG MAJ R STOUT MAJ D GODDARD MAJ C COGBURN 2402 E DRIVE BROOKS AFB TX 78235-5114	1	OSD/WHS/RE&F ATTN SEMD INDUS HYGIENE BR M SKOWRONSKI 1155 PENTAGON 2C431 WASHINGTON DC 20301-1155
1	HQ AFSC/SEGS ATTN LES KINKLE 9700 G AVE STE 230 KIRTLAND AFB NM 87117-5670	1	UNIFORMED SVC UNIV OF THE HEALTH SCIENCES DIR CLINICAL PSYCH PROGRAM DEPTS OF MED & CLIN PSYCH AND PREV MED & BIOMETRICS ATTN DR M FEUERSTEIN 4301 JONES BRIDGE ROAD BETHESDA MD 20814-4799
1	HQ AFMOA/SGOE ATTN OFC SURG GEN LTC S ZELNICK 110 LUKE AVE SUITE 400 BOLLING AFB WASHINGTON DC 20332-7050	1	ARL HRED AVNC FIELD ELEMENT ATTN AMSRL HR MJ (R ARMSTRONG) PO BOX 620716 BLDG 514 FT RUCKER AL 36362-0716
1	HQ MARINE CORPS (SD) ATTN IND HYGIENE PROG MGR DR J AKINYEMI 2 NAVY ANNEX ROOM 2403 WASHINGTON DC 20380-1775	1	ARL HRED MICOM FIELD ELEMENT ATTN AMSRL HR MO (T COOK) BUILDING 5400 ROOM C242 REDSTONE ARSENAL AL 35898-7290
1	OSHA US DOL N3653 DIR OFC OF ERG SPT DR R STEPHENS 200 CONSTITUTION AVE NW WASHINGTON DC 20210	1	ARL HRED USAADASCH FLD ELEMENT ATTN AMSRL HR ME (K REYNOLDS) ATTN ATSA CD 5800 CARTER ROAD FORT BLISS TX 79916-3802
2	NIOSH C PSYCHOPHYSIOLOGY & BIOMECHAN SECTION DR V P ANDERSON LT LIBBY COLE 4676 COLUMBIA PARKWAY MS C24 CINCINNATI OH 45226-1998	1	ARL HRED ARDEC FIELD ELEMENT ATTN AMSRL HR MG (R SPINE) BUILDING 333 PICATINNY ARSENAL NJ 07806-5000
1	NIOSH DIV OF SAFETY RSCH M/S P-198 ATTN DR L GARDNER 1095 WILLOWDALE ROAD MORGANTOWN WV 26505	1	ARL HRED ARMC FIELD ELEMENT ATTN AMSRL HR MH (J JOHNSON) BLDG 1109B 3RD FLOOR FT KNOX KY 40121-5215
1	OFC OF THE SEC OF DEFENSE OFC OF THE DPTY UNDERSECY OF DEF FOR ENVIRON SECURITY ASST FOR OCC HEALTH POLICY ATTN ODUSD (ES) SH LTC J SEIBERT 3400 DEFENSE PENTAGON WASHINGTON DC 20301-3400	1	ARL HRED CECOM FIELD ELEMENT ATTN AMSRL HR ML (J MARTIN) MYER CENTER RM 3C214 FT MONMOUTH NJ 07703-5630
		1	ARL HRED FT BELVOIR FIELD ELEMENT ATTN AMSRL HR MK (P SCHOOL) 10115 GRIDLEY ROAD SUITE 114 FORT BELVOIR VA 22060-5846

NO. OF
COPIES ORGANIZATION

1 ARL HRED FT HOOD FIELD ELEMENT
ATTN AMSRL HR MV (E SMOOTZ)
HQ TEXCOM BLDG 91012 RM 111
FT HOOD TX 76544-5065

2 ARL HRED NATICK FIELD ELEMENT
ATTN AMSRL HR MQ (M FLETCHER)
ATTN SSCNC A (D SEARS)
USASSCOM NRDEC BLDG 3 RM R-140
NATICK MA 01760-5015

1 ARL HRED FT HUACHUCA FLD ELEMENT
ATTN AMSRL HR MY (B KNAPP)
GREELY HALL (BLDG 61801 RM 2631)
FORT HUACHUCA AZ 85613-5000

1 ARL HRED FT LEAVENWORTH FLD ELE
ATTN AMSRL HR MP (D UNGVARSKY)
TPIO ABCS 415 SHERMAN AVE RM 327
FT LEAVENWORTH KS 66027-1344

1 ARL HRED FLW FIELD ELEMENT
ATTN AMSRL HR MZ (A DAVISON)
320 ENGINEER LOOP STE 166
FT LEONARD WOOD MO 65473-8929

1 ARL HRED OPTEC FIELD ELEMENT
ATTN AMSRL HR MR (D HEADLEY)
PARK CENTER IV RM 1450
4501 FORD AVENUE
ALEXANDRIA VA 22302-1458

1 ARL HRED SC&FG FIELD ELEMENT
ATTN AMSRL HR MS (L BUCKALEW)
SIGNAL TOWERS RM 207
FORT GORDON GA 30905-5233

1 ARL HRED STRICOM FIELD ELEMENT
ATTN AMSRL HR MT (A GALBAVY)
12350 RESEARCH PARKWAY
ORLANDO FL 32826-3276

1 ARL HRED TACOM FIELD ELEMENT
ATTN AMSRL HR MU (M SINGAPORE)
BLDG 200A 2ND FLOOR
WARREN MI 48397-5000

1 ARL HRED USAFAS FIELD ELEMENT
ATTN AMSRL HR MF (L PIERCE)
BLDG 3040 RM 220
FORT SILL OK 73503-5600

NO. OF
COPIES ORGANIZATION

1 ARL HRED USAIC FIELD ELEMENT
ATTN AMSRL HR MW (E REDDEN)
BLDG 4 ROOM 332
FT BENNING GA 31905-5400

1 ARL HRED USASOC FIELD ELEMENT
ATTN AMSRL HR MN (F MALKIN)
HQ USASOC BLDG E2929
FORT BRAGG NC 28307-5000

1 US ARMY RSCH DEV STDZN GP-UK
ATTN DR MICHAEL H STRUB
PSC 802 BOX 15
FPO AE 09499-1500

1 CDR US ARMY MEDICAL DEPT BOARD
ARMY MED DEPT SCHOOL AND CENTER
ATTN MCCS FBT
FORT SAM HOUSTON TX 78234-6124

1 US ARMY MED DEPT SCHOOL & CENTER
TRAINING DEVELOPMENTS OFC
ATTN MS BELINDA RAMIREZ
FORT SAM HOUSTON TX 78234

ABERDEEN PROVING GROUND

2 DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL CI LP (TECH LIB)
BLDG 305 APG AA

1 LIBRARY
ARL BLDG 459
APG-AA

1 ARL HRED ERDEC FIELD ELEMENT
ATTN AMSRL HR MM (R MCMAHON)
BLDG 459
APG-AA

2 US ARMY CHPPM
ATTN MCHB DC LTC SMITH
D M DOGANIERO CIH
APG EA

2 US ARMY CHPPM
ATTN MCHB DC OER LTC M LOPEZ
A CUTLER
APG EA

1 ARL SLAD
ATTN AMSRL BS (DR JT KLOPCIC)
BLDG 328 APG-AA

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	USMC LIAISON OFFICE ATTN AMST ML RYAN BUILDING APG-AA
1	USATECOM RYAN BUILDING APG-AA
1	COMMANDER CHEMICAL BIOLOGICAL AND DEFENSE COMMAND ATTN AMSCB CI APG-EA
1	CDN ARMY LO TO TECOM ATTN AMSTE CL TECOM HQ RYAN BLDG

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 1998		3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Standard and Alternate Methods of Stretcher Carriage: Performance, Human Factors, and Cardiorespiratory Responses				5. FUNDING NUMBERS AMS Code 622716.H700011 PR: 1L162716AH70 PE: 6.27.16	
6. AUTHOR(S) Knapik, J.J.; Harper, W.H.; Crowell, H.P.; Leiter, K.L.; Mull, B.T. (all of ARL)					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Human Research & Engineering Directorate Aberdeen Proving Ground, MD 21005-5425				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Human Research & Engineering Directorate Aberdeen Proving Ground, MD 21005-5425				10. SPONSORING/MONITORING AGENCY REPORT NUMBER ARL-TR-1596	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Eleven soldiers performed two-person carries of a stretcher containing an 80-kg manikin while walking on a treadmill set at 4.8 km/hr. In separate trials, soldiers carried the stretcher using one of four methods involving (a) traditional hand carriage, (b) shoulder straps (cross-shoulder system), (c) a specially designed harness that allowed load shifting between the hips and shoulders (hip-shoulder system), and (d) a clip that fit on the pistol belt of military load-carrying equipment (LCE) and placed the stretcher mass mainly on the hips (LCE system). With each system, subjects walked until fatigued or until 30 minutes expired. While subjects walked, their expired gases and heart rates were obtained and subjects rated their perceived exertion (Borg Scale). At the conclusion of all four trials, subjects rated each system on a number of subjective measures. Average (SD) carriage times (in minutes) were 2.7 +1.4, 14.5 +8.3, 25.4 +8.1, and 21.7 +9.9 with the hand, cross-shoulder, hip-shoulder, and LCE-integrated systems, respectively. Hand carriage resulted in considerably more cardiorespiratory stress (higher heart rate and minute ventilation) than the other three systems, but there were few consistent differences among the other three systems. Perceived exertion in the upper body was less with the hip-shoulder and LCE systems than with the other two systems, and subjects preferred the hip-shoulder and LCE integrated systems overall, as well as for specific characteristics including comfort, ease of use, and stability. These data indicate that two-person stretcher carriage methods that displace the load from the hands to the shoulders and hips improve performance, reduce cardiorespiratory stress, and are preferred by subjects. Further developmental work should focus on the hip-shoulder and LCE systems.					
14. SUBJECT TERMS ergonomics heart rate oxygen consumption fatigue muscle contraction utility analysis				15. NUMBER OF PAGES 97	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT		